Reviewed and approved for continued use on 12 May 1992.

Although the words "he," "him," and "his" are used sparingly in this manual to enhance communication, they are not intended to be gender driven nor to affront or discriminate against anyone reading this text.

Naval Education And Training Program Management Support Activity

AEROGRAPHER'S MATE SECOND CLASS, VOLUME 2

NAVEDTRA 10371

1990 Edition Prepared by
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PREFACE

This training manual (volume 2 of a 2 volume set) is one of a series of training manuals prepared for enlisted personnel of the Navy and Naval Reserve who are studying for advancement in the Aerographer (AG) rating. As indicated by the title, this manual is based upon the professional qualifications for the rate of AG2 as set forth in the *Manual of Qualifications for Advancement*, NAVPERS 18068 (Series).

The NRTC (Nonresident Training Course) is not included with this manual. Information on course administration and ordering is available in NAVEDTRA 12061.

This manual was prepared by the Naval Education and Training Program Management Support Activity, Pensacola, Florida, for the Chief of Naval Education and Training.

Your suggestions and comments on this manual are invited. Address them to Commanding Officer, NETPMSA, Building 2435, Pensacola, FL 32509-5000, Attention Code 0311.

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THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

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SUMMARY OF AEROGRAPHER'S MATE 2 TRAINING MANUALS

VOLUME 1

Aerographer's Mate 2, Volume 1, NAVEDTRA 10370 is designed to serve personnel in the AG rating. Subjects covered in this volume include: fundamentals of meteorology, atmospheric physics, atmospheric circulation, atmospheric phenomena, air masses, fronts, climatology, tropical meteorology, weather chart analysis, and imagery interpretation (satellite, radar, and LDATS (lightning detection and tracking system)).

VOLUME 2

Aerographer's Mate 2, Volume 2, NAVEDTRA 10371 covers the following areas: oceanography, oceanographic analysis, fundamentals of hydroacoustics, satellite imagery of oceanographic features, meteorological and oceanographic products and their interpretation, environmental briefings, special phenomena, products, and computations, briefing techniques, administration, and publications.

NONRESIDENT TRAINING COURSES

Two separate nonresident training courses are available for study and completion. Their titles and NAVEDTRA numbers are listed below:

Aerographer's Mate 2, Volume 1, NAVEDTRA 80370

Aerographer's Mate 2, Volume 2, NAVEDTRA 80371

UNIT 1

OCEANOGRAPHY AND OCEANOGRAPHIC ANALYSIS

FOREWORD

Over the years, the terms *aerographer* and *meteorologist* have, for the most part, become synonymous. Both terms pertain to individuals in the field of meteorology. What is not recognized by many is that aerographers also do considerable work in the field of oceanography.

Aerographers have always studied the atmospheric environment, and since the atmosphere directly impacts on the oceans of the world, aerographers have been given the responsibility of analyzing the ocean environment and predicting changes that occur within it.

The oceans of the world cover over 70 percent of Earth, and they are the reason that Earth is often referred to as the "water planet". Our Navy, as well as those of our adversaries, operates over, on, and under these oceans. Therefore, it is extremely important that our Navy know as much as possible about this environment.

Over the years the AG's role within the field of oceanography has been basic. Our responsibilities have been in the areas of observing and forecasting sea-surface temperatures, sea states, bathymetry profiles, and surf conditions. Today, however, more and more emphasis is being placed on improving our Navy's antisubmarine warfare capability. This increased emphasis requires that today's AG be far more knowledgeable of the ocean environment.

In this unit, we will discuss the sea surface in lesson 1, the ocean body in lesson 2, the ocean floor in lesson 3, and oceanographic analysis in lesson 4.

UNIT 1—LESSON 1

THE SEA SURFACE

ERVIEW	OUTLINE
:ognize the difference in ocean waves.	Waves
'ine *fetch* and *steady state.*	
'ine *surf* and recognize its controlling factors.	Surf
:ognize and explain the nearshore circulation :em.	Nearshore circulation
ntify the major ocean currents and their ations.	Major ocean currents
'ferentiate between sea ice and land ice.	Ice

THE SEA SURFACE

Man is in a unique position with regard Earth's atmosphere and the oceans. He :s at the bottom of one and at the top the other. The atmosphere is an ocean of and the seas, an ocean of water. In ny respects, the atmosphere and the oceans are ilar. For example, there are air currents and an currents, atmospheric waves (long and ›rt) and ocean waves, and the land (terrain) ieath the sea is much like that beneath the ıosphere.

Since the oceans of air and water interface and h has a definite impact on the other, let's begin he point of interface (the surface) and work vn.

Learning Objective: Recognize the difference between wind waves, swell waves, combined waves, and rogue or freak waves, and define *fetch* and *steady state*.

۱VES

Wind, atmospheric pressure changes, seismic turbances (such as earthquakes), and tidal attraction of the Sun and Moon all generate waves. However, since wind-generated waves are the most common waves, our discussion will center around their development and decay.

Wind Waves

Wind waves are one of the elements created by the interaction of the atmosphere and the sea surface. From small wavelets to high seas seas 12 feet or greater), wind waves are the result of the energy of the wind being imparted to the sea.

Waves of various proportions (heights and lengths) develop within a wave-generating area (a fetch). Figure 1-1-1 shows the variation in wind-wave heights as recorded by a wave-recording instrument. As you can see, the quite varied wave heights are random in nature. The height attained by wind waves is dependent on wind speed, the time the wind blows in one direction (duration), and the length of the fetch (the area over which the wind is blowing).

When all of the wind's energy is imparted to the sea within the fetch, the sea reaches a STEADY STATE. In a steady state, the waves

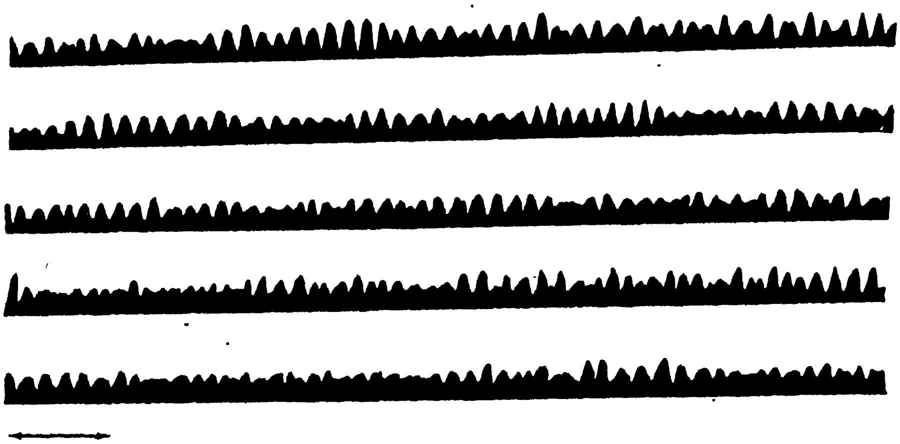

Figure 1-1-1.—Sea wave records.

Table 1-1-1.—Wind and Sea Scale for a Fully Arisen Sea

WIND AND SEA SCALE FOR FULLY ARISEN SEA														
SEA-GENERAL		WIND				SEA								
						WAVE HEIGHT FEET								
SEA STATE	DESCRIPTION	BEAUFORT WIND FORCE	DESCRIPTION	RANGE (KNOTS)	WIND VELOCITY (KNOTS)	AVERAGE	SIGNIFICANT	AVERAGE 1/10 HIGHEST	SIGNIFICANT RANGE OF PERIODS (SECONDS)	(PERIOD OF MAXIMUM ENERGY OF SPECTRUM)	AVERAGE PERIOD	AVERAGE WAVE LENGTH	MINIMUM FETCH (NAUTICAL MILES)	MINIMUM DURATION (HOURS)
0	Sea like a mirror.	U	Calm	Less than	0	0	0	0	-	-	-	-	-	-
	Ripples with the appearance of scales are formed, but without foam crests.	1	Light Airs	1 - 3	2	0.05	0.08	0.10	up to 1.2 sec	0.7	0.5	10 in.	5	18 min
	Small wavelets, still short but more pronounced; crests have a glassy appearance, but do not break.	2	Light Breeze	4 - 6	5	0.18	0.29	0.37	0-4-2.8	2.0	1.4	6.7 ft	8	39 min
1	Large wavelets, crests begin to break. Foam of glassy appearance. Perhaps scattered white horses.	3	Gentle Breeze	7 - 10	8.5	0.6	1.0	1.2	0-8-5.0	3.4	2.4	20	9.8	1.7 hrs
					10	0.88	1.4	1.8	1,0-6.0	4	2.9	27	10	2.4
2	Small waves, becoming larger; fairly frequent white horses.	4	Moderate Breeze	11-16	12	1 4	2.2	2.8	1.0-7.0	4.8	3.4	40	18	3.8
					13.5	1.8	2.9	3.7	1.4-7.6	5.4	3.9	52	24	4.8
3					14	2 0	3.3	4.2	1 5-7.8	5.6	4.0	59	28	5.2
					16	2.9	4.6	5.8	2.0-8.8	6.5	4.6	71	40	6.6
4	Moderate waves, taking a more pronounced long form; many white horses are formed. (Chance of some spray).	5	Fresh Breeze	17-21	18	3.8	6.1	7.8	2.5-10.0	7.2	5.1	90	55	8.3
					19	4.3	6.9	8.7	2.8-10 6	7.7	5.4	99	65	9.2
					20	5.0	8.0	10	3.0-11.1	8.1	5.7	111	75	10
5	Large waves begin to form; the white foam crests are more extensive everywhere. (Probably some spray).	6	Strong Breeze	22-27	22	6.4	10	13	3.4-12.2	8.9	6.3	134	100	12
					24	7 9	12	16	3.7-13.5	9.7	6.8	160	130	14
					24.5	8.2	13	17	3.8-13.6	9.9	7.0	164	140	15
6					26	9.6	15	20	4.0-14.5	10.5	74	188	180	17
	Sea heeps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind. (Spindrift begins to be seen).	7	Moderate Gale	28-33	28	11	18	23	4.5-15.5	11.3	7.9	212	230	20
					30	14	22	28	4.7-16.7	12.1	8.6	250	280	23
					30.5	14	23	29	4.8-17.0	12.4	8.7	258	290	24
					32	16	26	33	5.0-17.5	12.9	9.1	285	340	27
	Moderately high waves of greater length; edges of crests break into spindrift. The foam is blown in well marked streaks along the direction of the wind. Spray effects visibility.	8	Fresh Gale	34-40	34	19	30	38	5.5-18.5	13.6	9.7	322	420	30
7					36	21	35	44	5.8-19.7	14.5	10.3	363	500	34
					37	23	37	46.7	6.20.5	14.9	10.5	376	530	37
					38	25	40	50	6.2-20.8	15.4	10.7	392	600	38
					40	28	45	58	6.5-21.7	16.1	11.4	444	710	42
8	High waves. Dense streaks of along the direction of the wind. Sea begins to roll. Visibility affected.	9	Strong Gale	41-47	42	31	50	64	7-23	17.0	12.0	492	830	47
					44	36	58	73	7-24.2	17.7	12.5	534	960	52
					46	40	64	81	7-25	18.6	13.1	590	1110	57
	Very high waves with long overhanging crests. The resulting foam is in great patches and is blown in dense white streaks along the direction of the wind. On the whole the surface of the sea takes a white appearance. The rolling of the sea becomes heavy and shock-like. Visibility is affected.	10	Whole Gale	48-55	48	44	71	90	7.5-26	19.4	13.8	650	1250	63
9					50	49	78	99	7.5-27	20.2	14.3	700	1420	69
					51 5	52	83	106	8-28.2	20.8	14.7	736	1560	73
					52	54	87	110	8-28.5	21.0	14.8	750	1610	75
					54	59	95	121	8-29.5	21.8	15.4	810	1800	81
	Exceptionally high waves (Small and medium-sized ships might for a long time be lost to view behind the waves.) The sea is completely covered with long white patches of foam lying along the direction of the wind. Everywhere the edges of the wave crests are blown into froth. Visibility affected.	11	Storm	56-63	56	64	103	130	8-5-31	22.6	16.3	910	2100	88
					59.5	73	116	148	10-32	24	17.0	985	2500	101
	Air filled with foam and spray. Sea completely white with driving spray; visibility very seriously affected.	12	Hurricane	64-71.	>64	>80	>128	>164	101(35)	(26)	(18)	~	~	~

are at their maximum height and are FULLY DEVELOPED for the prevailing wind speed. As an example, if over a calm (no wind) 60-nautical-mile stretch of ocean a 20-knot southwesterly wind develops, the water ripples and then small wavelets develop. Eventually, all the energy of the 20-knot wind is imparted to the sea, and the waves become fully developed. Table 1-1-1 shows the wind-sea relationship for fully developed seas. For a 20-knot wind, it takes a minimum of 10 hours for a fully developed sea of 5- to 10-foot waves to develop.

When the wind is unable to impart its maximum energy to the waves, the sea does not fully develop. This can happen under two circumstances: (1) when the distance over which the wind blows is limited (the fetch is not long enough); or (2) when the wind is not in contact with the sea for a sufficient length of time (the wind hasn't been blowing long enough).

FETCH-LIMITED SEA.—When the fetch length is too short, the wind is not in contact with the waves over a distance sufficient to impart the maximum energy to the waves. The ranges of wave frequencies and heights are therefore limited. The wave frequencies are smaller and the wave heights are less than those of a fully developed sea. The wave generation process is cutoff before the maximum energy can be imparted to the waves and the fetch reaches a steady state. Therefore, for every wind speed, a minimum fetch distance is required for the waves to become fully developed. If this minimum fetch requirement is not met, the sea is fetch limited.

DURATION-LIMITED SEA.—When the wind is in contact with the sea for too short a period of time, it doesn't have enough time to impart the maximum energy to the sea. Any increase in wave frequencies and heights ceases before a fully developed state-of-the-sea commences. When this occurs, the sea is duration (time) limited. Therefore, every wind speed requires a minimum time for waves to become fully developed. If this time requirement is not met, the sea is duration limited. The state-of-the-sea classifications are as follows: fully developed, fetch limited, and duration limited.

Table 1-1-2 shows the minimum wind durations and fetch lengths needed to generate

Table 1-1-2.—Wind Speed and Minimum Fetch Length and Duration Necessary for a Fully Developed Sea

Wind Speed in Knots	Fetch Length in Nautical Miles	Duration in Hours
10	10	2.4
12	18	3.8
14	28	5.2
16	40	6.6
18	55	8.3
20	75	10
22	100	12
24	130	14
26	180	17
28	230	20
30	280	23
32	340	27
34	420	30
36	500	34
38	600	38
40	710	42
42	830	47
44	960	52
46	1,100	57
48	1,250	63
50	1,420	69
52	1,610	75
54	1,800	81
56	2,100	88

fully developed sea states for various wind speeds. When actual conditions fail to meet these minimum requirements, wave properties such as frequencies, lengths, and heights are determined by means of graphs or formulas.

Refer to table 1-1-1 again and notice that the wave height classifications are Average, Significant, and Highest 1/10. Average wave heights are based on the heights of all the waves observed, while significant wave heights pertain to the average height of the highest one-third of all the waves, and highest 1/10 pertains to the average height of the highest one-tenth of all the waves. In a fully developed fetch of 20-knot wind, average waves are 5 feet high, significant waves average 8 feet, and highest 1/10 average 10 feet.

As wind waves move beyond the fetch, they become swell waves (also known as "swell"). The transformation of wind waves to swell waves also occurs when the wind over the fetch dies off.

Swell Waves

On leaving a fetch, waves lose their energy source, and change their character. The height of the waves decrease, while the period increases. The height, period, and direction of these waves also become much more regular in comparison to wind waves.

The wave-dissipation process, or wave decay, is brought about by (1) internal friction within the waves, (2) resistance met as waves overtake the wind, (3) restraint caused by crosswinds, (4) action of ocean currents in the path of waves, and (5) effects of seaweed, ice, shoals, islands, or continents in the path of waves. Even with all these factors working to bring about wave dissipation, swell waves dissipate very gradually. As an example of such gradual dissipation, oceanographers at the University of California at San Diego tracked waves that developed in storms near Antarctica, crossed the equator and eventually reached the shores of Alaska. That's almost the entire length of the Pacific Ocean, or looked at in another way, halfway around the world.

Combined Waves

These waves come about when wind waves (ww) are superimposed on swell waves (sw). The interaction of wind waves and swell waves produces larger waves. However, observers do not report combined sea heights; they simply report the wind and swell. The resultant combined wave height (Cwh) is computed using the formula $Cwh = \sqrt{ww^2 + sw^2}$ or determined using combined sea-height tables (see table 1-1-3). Compute the combined-wave height using 8-foot wind waves and 15-foot swells. The combined height of these two waves works out to 17 feet, as follows:

$$
\begin{aligned}
Cwh &= \sqrt{ww^2 + sw^2} \\
&= \sqrt{8^2 + 15^2} \\
&= \sqrt{64 + 225} \\
&= \sqrt{289} \\
&= 17
\end{aligned}
$$

Now, use the combined sea-height table, using the same wind and swell wave heights, and you should come up with the same answer. If your answer is something other than 17 feet, you have misread the table.

Combined sea-height charts (analyses and prognoses) are most often produced at the oceanography centers and transmitted via radio facsimile. The importance of such charts to mariners is that it lets them know the highest seas or highest forecast seas in a particular operating area or along a particular route.

Rogue or Freak Waves

Rogue or Freak waves get their name from their height, which is abnormally high compared to the sea heights observed prior to the occurrence of this type of wave. The USS *Shreveport* encountered such a wave while operating in the Virginia Capes OPAREA. The wave washed over the *Shreveport's* bow and crashed into the superstructure at bridge level. It knocked out every window in the bridge, and men and equipment were battered. Prior to meeting this freak wave, the seas were normal, based on the wind conditions at the time. Such abnormal waves are highly infrequent and totally unpredictable. Oceanographers are not sure what causes these waves, but based on studies of encounters such as that of the USS *Shreveport*, oceanographers have found that these waves occur most frequently in areas of strong sea-surface temperature gradients. Such gradients exist where cold and warm sea currents meet. One such area is the "North Wall" of the Gulf Stream, off Cape Hatteras. Another area exists along the coast of

Table 1-1-3.—Combined Sea-height Table

WIND-WAVE HEIGHT

SWELL WAVE HEIGHT		5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	5	7	8	9	9	10	11	12	13	14	15	16	17	18	19	20	21
	6	8	8	9	10	11	12	13	13	14	15	16	17	18	19	20	21
S	7	9	9	10	11	11	12	13	14	15	16	17	17	18	19	20	21
W	8	9	10	11	11	12	13	14	14	15	16	17	18	19	20	21	22
E	9	10	11	11	12	13	13	14	15	16	17	17	18	19	20	21	22
L	10	11	12	12	13	13	14	15	16	16	17	18	19	20	21	21	22
L	11	12	13	13	14	14	15	16	16	17	18	19	19	20	21	22	23
	12	13	13	14	14	15	16	16	17	18	18	19	20	21	22	22	23
W	13	14	14	15	15	16	16	17	18	18	19	20	21	21	22	23	24
A	14	15	15	16	16	17	17	18	18	19	20	21	21	22	23	23	24
V	15	16	16	17	17	17	18	19	19	20	21	21	22	23	23	23	25
E	16	17	17	17	18	18	19	19	20	21	21	22	23	23	24	25	26
	17	18	18	18	19	19	20	20	21	21	22	23	23	24	25	25	26
H	18	19	19	19	20	20	21	21	22	22	23	23	24	25	25	26	27
E	19	20	20	20	21	21	21	22	22	23	23	23	25	25	26	27	28
I	20	21	21	21	22	22	22	23	23	24	24	25	26	26	27	28	28
G	21	22	22	22	22	23	23	24	24	25	25	26	26	27	28	28	29
H	22	23	23	23	23	24	24	25	25	26	26	27	27	28	28	29	30
T	23	24	24	24	24	25	25	25	26	26	27	27	28	29	29	30	30
	24	25	25	25	25	26	26	26	27	27	28	28	29	29	30	31	31
	25	25	26	26	26	27	27	27	28	28	29	29	30	30	31	31	32

South Africa, where the cold Benguela Current meets the warm Alguhas Stream.

Learning Objective: Define *surf*, and recognize the factors that affect it.

SURF

Waves originating in distant storms often travel as long low swells that are scarcely noticeable until they near a shore and become surf. Surf is defined as swell that breaks upon the shore. As the swell is deflected and scattered by outlying islands and bent around points into bays, the wave crests become oriented parallel to the shoreline. Hence, there is often considerable variation in surf characteristics.

As the incoming waves enter water of a depth less than one-half their wavelength, the waves feel the bottom. For example, a wave train with wavelengths of 90 feet is affected by the bottom when the depth of the water becomes 45 feet or less. When waves feel bottom, their wavelength decreases, they become more steep, and their height may change.

Factors influencing local surf conditions are as follows: the height, period, length, and direction of the incoming wave train, the winds near shore, bottom and beach topography, the angle of the breakers with the shoreline, the distance of the outermost breakers from the shoreline, and the average water depth at the point of breaking. Some of these factors are also important in establishing and maintaining the nearshore circulation system.

Learning Objective: Recognize and explain the nearshore circulation system.

NEARSHORE CIRCULATION

Two interrelated current systems may appear near the shore. They are the coastal current system and the nearshore current system. The COASTAL

SYSTEM is a relatively uniform drift that flows roughly parallel to shore. It may be composed of tidal currents, wind-driven currents, or local, density-driven currents. The NEARSHORE SYSTEM is more complex and is composed of shoreward moving water in the form of waves at the surface, a return flow or drift along the bottom in the surf zone, nearshore currents that parallel the beach (longshore or littoral), and rip currents. See figure 1-1-2.

Longshore Currents

Longshore or littoral currents occur in the surf zone and are caused by waves approaching the beach at an angle. If you ever swim in the surf where ocean waves are approaching the beach at an angle, you will most likely become aware of the longshore current.

Most people like to swim in the immediate proximity of the beach where they enter the water. However, what many swimmers find out after being in the water awhile is that they are transported quite a distance from where they entered the water. The transporting mechanism is the longshore current.

At times the current is almost imperceptible, but at other times, it can be quite strong. Generally, longshore currents increase with (1) increasing breaker height, (2) increasing breaker-crest speed, (3) increasing angle between breaker crests and bottom contours, and (4) decreasing wave period. Also, under otherwise identical conditions, a steep beach will have a stronger longshore current than a more gently sloping beach. Another factor to consider is development of a longshore sandbar. These bars channel the current in the trough between the bar and the beach, and quite a strong current can result.

Rip Currents

Rip currents are quite often erroneously called "rip tides". A rip current is not associated with the tides, but is caused by the return flow of water from the beach. The current resembles a small jet or neck in the breaker zone, which fans out behind the breakers and becomes quite diffuse. The current extends from the surface to the bottom and is quite strong. The strength or intensity of rips is not predictable, but is determined using the same factors that control longshore currents. The speed of feeder currents flowing into the jet increases as they near the jet.

Rip currents may or may not occur along a stretch of beach. When they occur, they may be irregularly spaced, or regularly spaced at long or short intervals. They commonly form at the down-current end of a beach where a headland (a point where the land juts out into the water) deflects the longshore current seaward.

Learning Objective: Identify the major ocean currents and their locations, and recognize their effects on the weather.

MAJOR OCEAN CURRENTS

The major ocean currents are established and maintained by the stresses exerted by the prevailing winds. Thus, the oceanic circulation pattern roughly corresponds to Earth's atmospheric circulation pattern. Since the air circulation over the oceans in the middle latitudes is chiefly anticyclonic (more pronounced in the Southern Hemisphere than in the Northern Hemisphere), the oceanic circulation is more or less the same. At higher latitudes, where the windflow is principally cyclonic, the oceanic circulation follows this pattern, although not as closely as the anticyclonic pattern of the middle latitudes. In regions of pronounced monsoonal flow, the monsoon winds control the currents. The general distribution of ocean currents is as follows:

- At middle (below 40° lat.) and low latitudes, warm currents flow poleward along the eastern coasts of continents and cold currents flow equatorward along the western coasts. This is true in both hemispheres.

- In the Northern Hemisphere at high latitudes, cold currents flow equatorward along the east coasts of continents, and warm currents flow poleward along the western coasts.

- In monsoonal regions, ocean currents vary with the seasons, and irregular coastlines can cause deviations in the general distribution of ocean currents.

The oceanic circulation pattern acts to transport heat from one latitude belt to another in a manner similar to the heat transported by the primary circulation of the atmosphere. The cold waters of the Arctic and Antarctic move

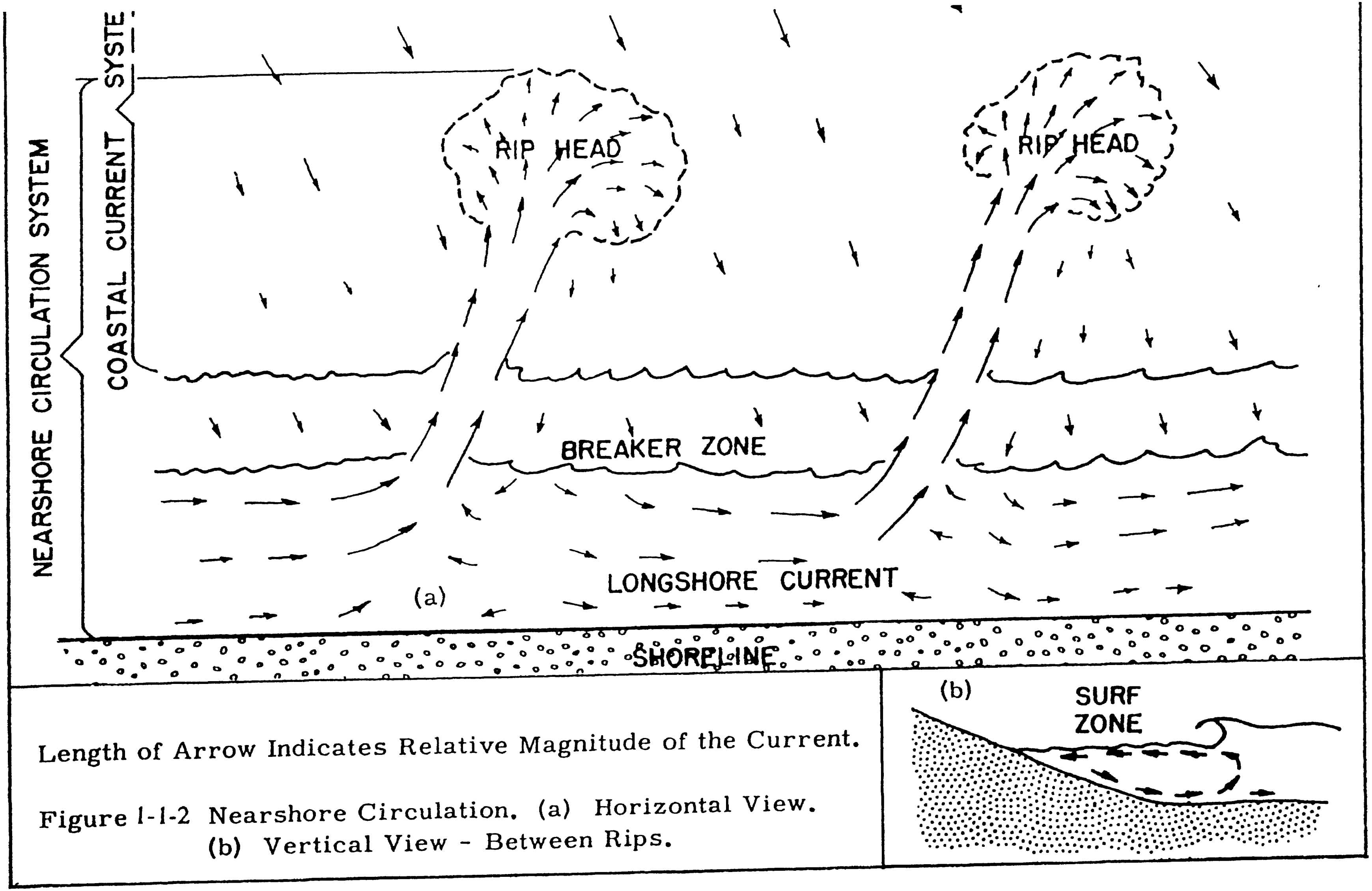

Figure 1-1-2.—Nearshore circulation. (a) Horizontal view; (b) vertical view, between rips.

equatorward toward warmer water, while the warm waters of the lower latitudes move poleward. The effect this circulation pattern has on climate can be seen in the comparatively mild climate that exists in the area of northwest Europe. Even in winter, Norwegian ports along the Atlantic are ice-free most of the time. This is due to the effect of the warm ocean current that sweeps northward along the Norwegian coast. In contrast, a cold ocean current flows equatorward along the coast of California and is a major reason that cities such as San Francisco experience relatively cool summer temperatures. Figure 1-1-3 shows the surface currents of the oceans during February and March.

North Atlantic Currents

The North Atlantic Ocean is dominated by the NORTH EQUATORIAL CURRENT and the GULF STREAM SYSTEM.

NORTH EQUATORIAL CURRENT.—The North Equatorial Current is located in the trade wind belt of the North Atlantic Ocean. The chief sources of the flow are the northeasterly currents off the west coast of northwestern Africa. These currents of water of relatively high density and low temperature are an extension of the North Atlantic Current. They help lower the temperatures along the northwest coast of Africa. The temperatures near the coast are further lowered by UPWELLING. Upwelling of ocean water is a process by which winds push surface water away from the coast. Colder subsurface water then moves up and replaces the surface water. In the Northern Hemisphere, upwelling is common where the wind blows parallel to the coast, with the coast on the left side of the wind. The upwelling process affects only the upper layers of the ocean (the maximum depth being about 150 fathoms or 900 feet).

As the North Equatorial Current flows westward north of the equator, the South Equatorial Current crosses the equator and joins it in the western North Atlantic Ocean. Consequently, that part of the North Equatorial

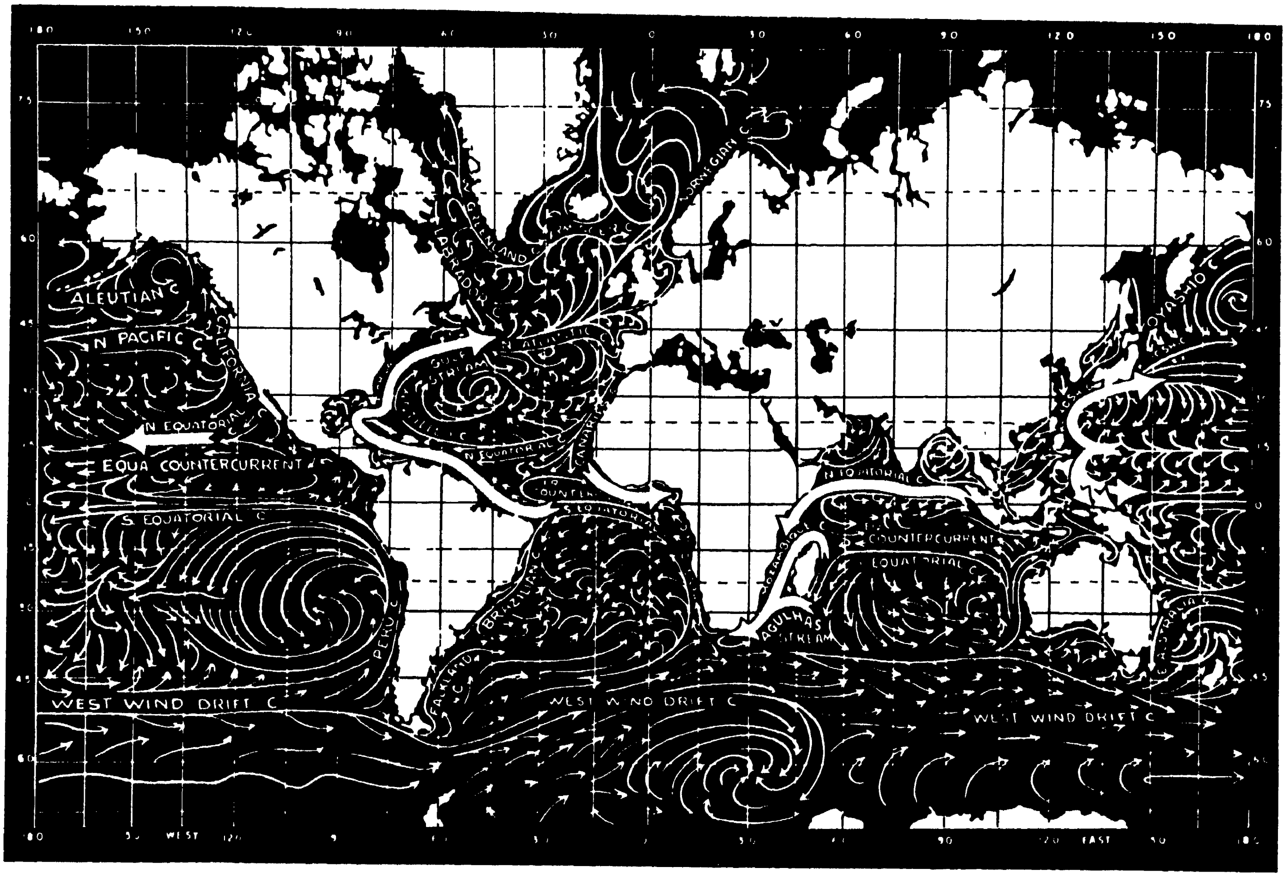

Figure 1-1-3.—Surface currents of the oceans (February-March).

Current that enters the Caribbean Sea has water that is a mixture of waters from the North Atlantic Ocean and South Atlantic Ocean.

ANTILLES CURRENT.—The Antilles Current is the western extension of the North Equatorial Current. It flows along the northern side of the Greater Antilles. It carries water that is virtually the same as that of the Sargasso Sea (a portion of the middle North Atlantic Ocean).

GULF STREAM SYSTEM.—The Gulf Stream system begins in the Florida Straits and flows northward and eastward along the east coast of the United States. This system, along with the Kuroshio System of the western Pacific, is the fastest of all the ocean currents. It moves with speeds of 25 to 75 miles per day or roughly 1 to 3 knots. The Gulf Stream system is made up of three currents: the FLORIDA CURRENT, GULF STREAM, and NORTH ATLANTIC CURRENT.

Florida Current.—The Florida current extends from the Florida Straits to Cape Hatteras. Much of the flow is derived from the Caribbean Sea by way of the Yucatan Channel; the water from the Yucatan Channel takes the shortest route to the Florida straits rather than making a long sweep through the Gulf of Mexico. The Florida Current is also fed by the Antilles Current.

Oceanographers believe that the energy of the Florida Current comes from the difference in the levels of the water in the Gulf of Mexico and the water adjacent to the Florida coast, the waters in the Gulf being higher. The difference in the two levels is due to the prevailing winds which result in the piling up of water in the Gulf of Mexico.

Gulf Stream.—The Gulf Stream is the middle portion of the Gulf Stream System. It begins near Cape Hatteras and continues northward to the vicinity of the Grand Banks off Newfoundland. To the right of the Gulf Stream is the Sargasso Sea portion of the North Atlantic Ocean, and to the left are coastal and slope waters.

North Atlantic Current.—The North Atlantic Current begins off the Grand Banks, where the Gulf Stream begins to fork. It consists of northerly and easterly currents terminating in subsidiary currents. One of the major subsidiaries is the IRMINGER CURRENT, which flows westward off the southern coast of Iceland. Another is the NORWEGIAN CURRENT. It flows beyond the Norwegian Sea into the polar seas. Other branches of the North Atlantic Current, turning southward, end in huge eddies off the coast of Europe and in the relatively cold CANARIES CURRENT off the northwest coast of Africa.

North Pacific Currents

The currents of the North Pacific Ocean are very similar to the currents of the North Atlantic Ocean. Even so, there are some distinct differences. These differences are due mainly to the large amounts of subarctic water in the North Pacific, compared with the small amount in the North Atlantic.

NORTH EQUATORIAL CURRENT.—The North Equatorial Current of the North Pacific Ocean starts near the western coast of Central America. Waters of the CALIFORNIA CURRENT and other western and eastern North Pacific currents feed into it as it flows west. Toward the western side of the North Pacific most of the waters turn northward along the eastern coast of the northern Philippines and Formosa; some of the waters turn southward and become a part of the EQUATORIAL COUNTERCURRENT. Consequently, the North Equatorial Current takes very warm water to the eastern side of the island systems in the western Pacific.

CROMWELL CURRENT.—The Cromwell current is a narrow, swift subsurface current centered on the equator between 2°N and 2°S. It flows from west to east between 140°W and 92°W. At the equator, the easterly flow begins at approximately 20 meters and disappears at roughly 250 meters. It reaches a maximum speed of 2 to 2.5 knots at 100 meters.

KUROSHIO SYSTEM.—The Kuroshio system is quite similar to the Gulf Stream system of the North Atlantic Ocean. It begins where the North Equatorial Current leaves off. It flows past Formosa and proceeds northeastward in the deep ocean area between the China Sea and the Ryukyu Islands. The system flows eastward and northeastward along the coast of Japan.

Like the Gulf Stream system, the Kuroshio system has three branches: the KUROSHIO CURRENT, KUROSHIO EXTENSION, and NORTH PACIFIC CURRENT.

Kuroshio Current.—The Kuroshio corresponds to the Florida Current of the Gulf Stream system. It flows from Formosa to about 35 °N. The salinity is less than that of the Florida Current, and cold offshore winds cause an annual range in sea-surface temperature of as much as 9 °C in some localities.

Kuroshio Extension.—As the name implies, this current is an extension of the warm Kuroshio Current. It begins near 35 °N, where the Kuroshio splits. The major well-defined portion of this current flows eastward to about 160 °E. The other branch flows northeastward to about 40 °N, where it turns eastward.

North Pacific Current.—The North Pacific Current is not well-defined, and tracing its path across the Pacific is difficult. Temperature and salinity provide the best indications of its location. The current is most recognizable between 160° and 150 °W, but much of the waters turn southward before reaching 150 °W, forming many of the major whirls found in this portion of the North Pacific.

South Atlantic Currents

The prevailing anticyclonic wind circulation of the Southern Hemisphere gives the South Atlantic Ocean its characteristic ocean circulation.

SOUTH EQUATORIAL CURRENT.—This current dominates the northern portion of the South Atlantic Ocean. It flows from east to west just south of the EQUATORIAL COUNTERCURRENT. On reaching the eastern shores of South America, it splits. One branch turns northward along the northern coast of South America, where it merges with waters of the North Equatorial Current. The other branch flows southward as the BRAZILIAN CURRENT.

BRAZILIAN CURRENT.—The Brazilian Current brings very warm, saline waters to the coasts of Brazil and Uruguay. It flows south along the east coast of South America to about 40 °S, where it turns east and joins the FALKLAND CURRENT. The Falkland Current is an extension of the WEST WIND DRIFT CURRENT.

WEST WIND DRIFT CURRENT.—This cold current flows west to east and completely encircles the Antarctic continent. Because it encircles Antarctica, it is also referred to as the ANTARCTIC CIRCUMPOLAR CURRENT. In the South Atlantic the West Wind Drift flows east between 45 °S and 50 °S. The FALKLAND CURRENT, which flows north along the coast of Argentina, and the BENGUELA CURRENT, which flows north along the west coast of South Africa, are both extensions of the West Wind Drift Current.

FALKLAND CURRENT.—The Falkland Current brings cold waters of low salinity as far north as 40 °S before turning east and merging with the Brazilian Current. The two currents develop great whirls in the middle section of the South Atlantic Ocean.

BENGUELA CURRENT.—The Benguela Current is the dominant current in the eastern South Atlantic. It flows north along the west coast of Africa, and its cold waters are a major contributor to the formation of low clouds and fog along the immediate southwestern coast.

GUINEA CURRENT.—The Guinea Current is an extension of the Equatorial Countercurrent. It flows eastward to the African coast.

South Pacific Currents

The currents of the South Pacific Ocean, like those of the South Atlantic Ocean, show the effects of the atmosphere's anticyclonic circulation.

SOUTH EQUATORIAL CURRENT.—The northern South Pacific is dominated by the South Equatorial Current. It flows east to west just south of the Equatorial Countercurrent. On reaching its western limit, it turns southward and becomes the EAST AUSTRALIAN CURRENT.

EAST AUSTRALIAN CURRENT.—The East Australian Current is an extension of the South Equatorial Current. It flows south along Australia's east coast and brings warm waters to the northern and western coasts of New Zealand. As a result, the eastern coast of Australia and the western coast of New Zealand are warmer than their opposite coasts. At its southern limit, the East Australian Current meets the West Wind Drift Current. The West Wind Drift Current flows across the Pacific along or around the 50th parallel, where a branch flows north as the PERU or HUMBOLDT CURRENT.

PERU OR HUMBOLDT CURRENT.—The Peru Current dominates the coastal waters of western South America. The waters are relatively cold, and there is considerable upwelling off the coasts of Chile and Peru. Coastal fogs and low clouds are characteristic of the area.

Seas Adjacent to the North Atlantic

There are several currents in seas adjacent to the North Atlantic Ocean that are of considerable importance.

MEDITERRANEAN SEA.—There is a strong current in the Strait of Gibraltar. Here, the waters of the North Atlantic flow into the Mediterranean Sea in the upper layers, and waters of the Mediterranean flow into the North Atlantic in the lower layers. The outflowing waters are colder and have a higher salinity than the waters flowing into the Mediterranean.

LABRADOR SEA AND BAFFIN BAY.— Waters of the North Atlantic Ocean enter the Labrador Sea along the west coast of Greenland as the WEST GREENLAND CURRENT. Some of this current flows through the Davis Strait into Baffin Bay, while the remainder turns westward and joins the LABRADOR CURRENT. The Labrador Current flows southward along the east coast of Labrador. A portion of this current turns eastward and flows along the northern border of the North Atlantic Drift. Another portion flows south along the east coast of North America to the vicinity of Cape Hatteras.

CARIBBEAN SEA AND GULF OF MEXICO.—The strong westerly current that flows through the Caribbean Sea and Yucatan Channel is a continuation of the southern branch of the North Equatorial Current of the Atlantic Ocean. Two conspicuous eddies accompany this current; one eddy is in the bay between Nicaragua and Colombia, while the other is between Cuba and Jamaica.

To the west of the Yucatan Channel most of the main current turns east and joins the Florida Current through the Florida Straits. Another portion flows into the Gulf of Mexico, where pronounced eddies dominate the circulation. These eddies are caused by the contours of the coast and the character of the Gulf floor.

Other North Pacific Currents

For the picture of the oceanic circulation in the North Pacific Ocean to be complete, several other currents of adjacent seas must be mentioned.

ALEUTIAN CURRENT.—The Aleutian Current flows east poleward of the North Pacific Current and separates at the Aleutian Islands. One branch flows north of the islands. It enters the Bering Sea, where it circulates in a counterclockwise manner before flowing south through the Bering Strait and joining the OYASHIO CURRENT.

The other branch flows south of the Aleutians. On approaching the coast of North America, one portion turns north and flows into the Gulf of Alaska, while the other flows south and becomes the CALIFORNIA CURRENT. The portion that flows into the Gulf of Alaska is a warm current. It brings milder winter temperatures to southern Alaska than would normally be expected at that latitude. On the other hand, the southward flowing branch is a cold current.

OYASHIO CURRENT.—The Oyashio Current flows south from the vicinity of the Bering Strait to the northern islands of Japan. It divides at 40°N. One branch turns east and joins the Kuroshio Current. The other branch flows south along Japan's eastern coast.

In the winter, the Oyashio carries cold waters as far south as Vietnam, but in the summer, the summer monsoon restricts the Oyashio to the area north of 40°N.

CALIFORNIA CURRENT.—The California Current flows southward along the west coast of North America. In the spring and summer these cool waters have a definite cooling effect on the western coast of the United States. The prevailing north-northwest winds also create a great deal of upwelling, which adds to the cooler air temperatures of this area. Where the upwelling is intense, the spring temperatures are colder than the winter temperatures. In the areas of moderate upwelling, the winter temperatures are colder. The upwelling process ceases in the fall and gives way to a surface countercurrent known as the DAVIDSON CURRENT.

DAVIDSON CURRENT.—This current exists in the fall and winter and flows northward along the California coast to about 48°N.

Indian Ocean Currents

The Asiatic Monsoon influences the currents of the North Indian Ocean, while the currents of the South Indian Ocean are influenced by the atmosphere's anticyclonic circulation.

NORTH EQUATORIAL CURRENT.—During the northwest monsoon (February and March), the wind blows from the continent and aids in the development of the North Equatorial Current. The current flows from east to west; and upon reaching the east coast of Africa, a good portion turns southward, crosses the equator, and becomes the MOZAMBIQUE CURRENT. A strong countercurrent exists south of the North Equatorial Current at this same time of year.

In August and September, during the southwest monsoon, the North Equatorial Current reverses and flows west to east as the MONSOON CURRENT. At the same time, the countercurrent seems to disappear.

MOZAMBIQUE CURRENT.—The Mozambique Current flows south along the east coast of Africa from the vicinity of the equator to about 35 °S, where it becomes known as the ALGUHAS STREAM.

ALGUHAS STREAM.—The Alguhas Stream flows westward along the southern coast of Madagascar and joins the Mozambique Current along the east African coast. From there it flows south to the southern tip of Africa (the Cape of Good Hope), where a good portion joins up with the West Wind Drift Current.

WEST WIND DRIFT CURRENT.—The West Wind Drift Current flows across the Indian Ocean to the waters southwest of Australia. Here it splits; one branch continues east along the southern coast, while the other flows northward along the western coast. This branch brings relatively cool waters to the western Australian coast and contributes to the formation of fog and low stratus clouds over the region.

In general, the following statements may be made concerning the effects ocean currents have on weather:

1. West coasts of continents in tropical and subtropical latitudes (except close to the equator) are bordered by cool waters. Their average temperatures are relatively low with small diurnal and annual ranges. There is fog, but generally the areas (southern California, Morocco, etc.) are arid.

2. West coasts of continents in middle and higher latitudes are bordered by warm waters which cause a distinct marine climate. They are characterized by cool summers and relatively mild winters with a small annual range of temperatures (upper west coasts of the United States and Europe).

3. Warm currents parallel east coasts in tropical and subtropical latitudes. This results in warm and rainy climates. These areas lie in the western margins of the subtropical anticyclones and are relatively unstable (Florida, the Philippines, Southeast Asia).

4. East coasts in the lower middle latitudes (leeward side) have adjacent warm waters that produce a modified continental-type climate. The winters are fairly cold, and the summers are warm or hot.

5. East coasts in the higher middle latitudes have adjacent cool ocean currents, with subsequent cool summers.

Indirectly, ocean currents also influence the location of the primary frontal zones and the tracks of cyclonic storms. Located off the eastern coast of the United States in winter are two of the major frontal zones. These zones occur where the sea-surface temperature gradient is steep and a large amount of tropical water is transported into the middle latitudes. This places these fronts where large amounts of energy are available. This area contrasts with the strictly cold, eastern continental United States and suggests that the development of cyclones (low-pressure centers) along these fronts may be of thermodynamic origin.

Two of the main hurricane tracks in the Atlantic also appear to be associated with warm waters. One follows the warm waters through the Caribbean, and the other follows the waters off the northern and eastern coasts of Florida and the Greater Antilles. Extratropical cyclones of fall and winter also appear to be attracted to warm waters.

Learning Objective: Describe the formation of ice on the surface of the sea, and differentiate between sea ice and land ice.

ICE

Roughly 3% of the world's water surfaces are ice covered. In the polar seas, submarines transit beneath the ice-covered water, while surface ships operate in and around the ice. From a safety standpoint, all ships must be aware of where ice lies in relation to their position.

The two main types of ice found in the seas and oceans are sea ice, which accounts for 95% of the total coverage, and glacier ice. The Naval Polar Oceanography Center at Suitland, Maryland, keeps the fleet advised of the development, movement, and the equatorward limit of sea ice, and the location and movement of icebergs. This is done through the issuance of global sea-ice analyses and forecasts.

Sea Ice

We know that pure water freezes at 0 °C, but the freezing point of sea water varies depending on salinity. See figure 1-1-4. Under average salinity conditions (35 ‰), sea water begins to freeze at −1.9 °C. However, before surface waters will freeze, the entire water column must cool to its temperature of maximum density. Therefore, shallow waters (of low salinity—less than 24.7 ‰) freeze more rapidly than deeper water. As you can see, the freezing of sea water is governed primarily by temperature, salinity, and depth; however, this ice formation can be retarded by winds, currents, and tides.

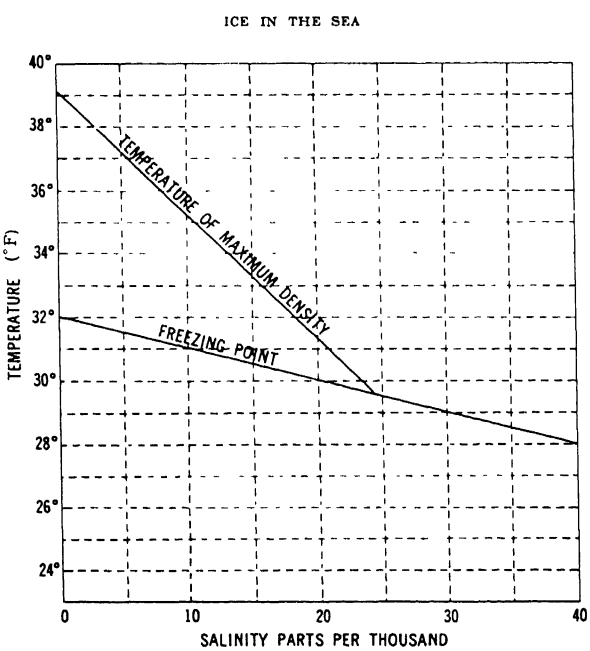

Figure 1-1-4.—Relationship between temperature of maximum density and freezing point for water of varying salinity.

In the open sea, the first sign that the sea surface is freezing is an oily opaque appearance of water. This appearance is caused by the formation of minute ice needles (spicules) and thin plates of ice (frazil crystals). As the formation process continues, the surface attains a thick soupy consistency termed grease ice. Next, depending on the wind, waves, and salinity, an elastic or brittle crust forms. The elastic crust (nilas) has a matte appearance, while the brittle crust (ice rind) is shiny. As the crust thickens, the wind and sea cause the ice to break up into rounded masses known as pancake ice. With continued freezing, the pancake ice forms into a continuous sheet.

The formation of sea ice usually begins with the onset of autumn, and the first ice usually appears in the mouths of rivers that empty into shallow seas, such as that off northern Siberia. During the increasingly longer and colder nights of autumn, ice forms along the shorelines (fast ice) and becomes a semipermanent feature that widens and spreads. When islands are close together, as in the Siberian Sea, fast ice blankets the sea surface, and bridges the waters between all land areas.

On the average in the Northern Hemisphere, sea ice is at a minimum in September, while at a maximum in March. In the Southern Hemisphere these times are nearly opposite; minimum in March and maximum in September.

SEA ICE CLASSIFICATION.—Sea ice is subdivided into young ice, first-year ice, and old ice.

Young Ice.—This ice forms in one year or less, and its thickness ranges from 10 to 30 centimeters (4 to 12 inches). It is further classified as gray ice and gray-white ice.

First-year Ice.—This ice is a more or less unbroken level of ice of not more than one winter's growth that starts as young ice. Its thickness is from 30 centimeters to 2 meters (1 foot to 6 1/2 feet). First-year ice may be subdivided into thin first-year ice, medium first-year ice, and thick first-year ice. The latter is more than 4 feet thick.

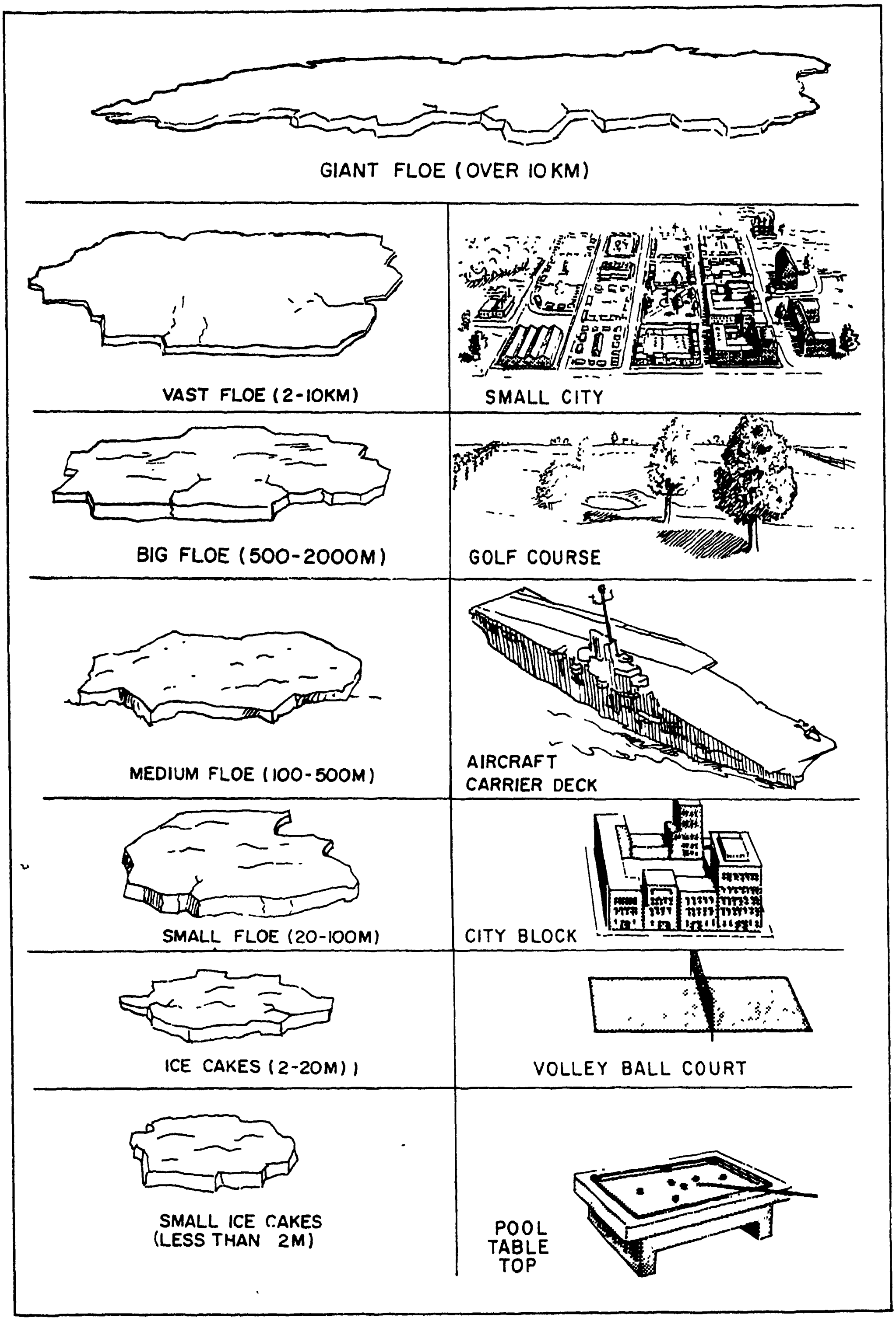

Figure 1-1-5.—Sizes of sea ice.

Old Ice.—Old ice is extremely heavy sea ice ɜt has survived at least one summer's melt. It curs primarily in the arctic and antarctic polar cks as a vast mass of converging, crushing, and /iding ice floes of various ages, sizes, shapes, d thicknesses that drift around the Arctic Basin d Antarctica. Old ice may be subdivided into :ond-year ice and multi-year ice.

SIZE.—Generally, sea ice is categorized into /en sizes. Refer to figure 1-1-5 for relative sizes d a comparison to other more common ıtures.

TOPOGRAPHY.—The terms most fre- ently used to describe the topography, or nfiguration of the ice surface, are related to ɜ degree of surface roughness. Figure 1-1-6 ıstrates the following types of topography:

Rafted Ice. This type of topography occurs ıen ice cakes override one another. Rafting curs when wind forces ice cakes or ice floes ʒether. It is associated with young and first-year '.

Ridged Ice. Ridged ice is much rougher than 'ted ice and occurs with first-year ice. Wind and 'ather can eventually smooth the surface of the lges.

Hummocked Ice. Hummocking occurs with ǀ ice. It is defined as ice piled haphazardly into ɔunds or hillocks. At the time of its formation, mmocked ice is similar to rafted ice; the ıjor difference being that the hummocked ice, because of its thickness, requires a greater degree of pressure and heaping.

DRIFT. Drift refers to sea ice, as well as broken off portions (outer edges) of fast ice that move along with wind, tides, and currents.

Direction.—Pack ice, sea ice covering more than half of the visible sea surface, usually drifts to the right of the true wind in the Northern Hemisphere (left in the Southern Hemisphere). Observations show that the actual drift is about 30° from that of the wind direction, or very nearly parallel to the isobars on a weather map. The drift more closely follows the wind in winter than in summer. In summer, the tides play a bigger role in the movement of the ice.

Speed.—A close estimate of the speed of drifting pack ice is possible using the wind speed. On the average, the drift of ice in the Northern Hemisphere ranges from 1.4% of the wind speed in April, to 2.4% of the wind speed in September. Although wind is the primary driving force, the presence or absence of open water in the direction of the drift greatly influences the speed of drift. Ice-free water in the direction of the drift, no matter how distant, permits the pack ice to drift freely in that direction. Ice-clogged water, on the other hand, slows the ice's forward movement.

WATER FEATURES.—Naval operations in and around fields of sea ice can be hazardous. The movement of massive floes of ice can cut off ships from open water, and worse yet, the ice may close in around a ship, leaving it stranded in a sea

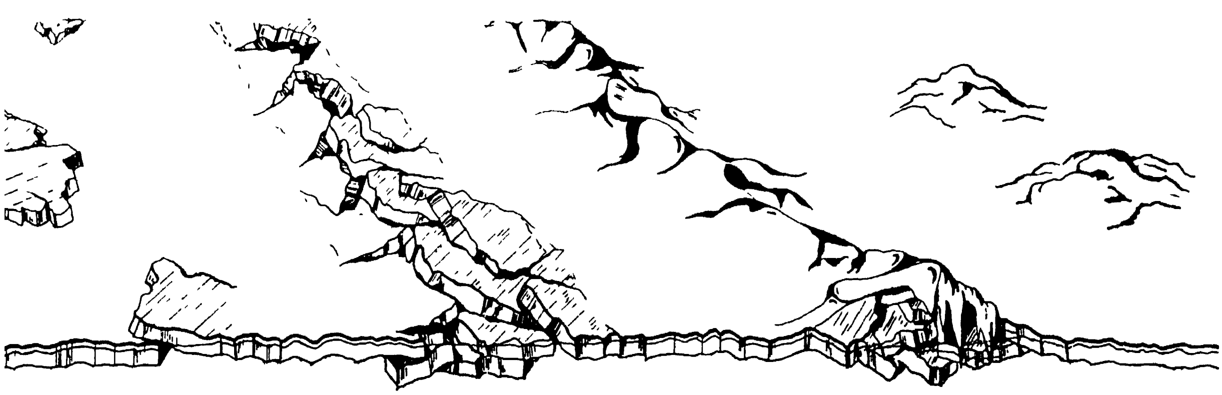

Figure 1-1-6.—Various types of ice topography caused by pressure.

of ice. Therefore, open water in ice-covered seas becomes very important.

There is a great variety of water features associated with sea ice. Some of the most common features are as follows:

Fracture. Any break through the ice.

Lead. A long, narrow break or passage through the ice; a navigable fracture. A lead may be open or refrozen.

Puddle. A depression in sea ice usually filled with melted water caused by warm weather.

Thaw holes. Holes in the ice that are caused by the melting associated with warm weather.

Polynya. Any sizable area of seawater enclosed by sea ice. Put another way, simply a large hole in the ice.

Land Ice

Ice of land origin, glacier, ice is composed initially of large accumulations of compacted snow that reach the sea as coastal glaciers and ice shelves. The leading edges of these glaciers break off (calve) and fall into the sea. This ice then drifts to sea as ICEBERGS.

ICEBERGS.—Since 86% of the world's glaciers occur in Antarctica, most icebergs originate around that continent. Most of the remainder of the world's glaciers are located in Greenland. Greenland is the main source of icebergs in the Northern Hemisphere (about 90%). Nearly 70% of Greenland's icebergs originate along the western coast near 68 °N.

Classification.—Icebergs are pinnacled (cone-shaped) or tabular (flat-topped and straight-sided). See figure 1-1-7. The structure, and to some extent the appearance, depends upon the ice that produces the berg. Pinnacled or irregular-shaped bergs come from glaciers that plow across uneven ground on their way to the tidewater, while the tabular bergs come from ice shelves that thrust directly out to sea. Pinnacled and irregular bergs are most prevalent in the Northern Hemisphere, while the tabular bergs are more prevalent in the Southern Hemisphere.

Size and Depth.—Icebergs originating in Greenland average 70 meters in height and 280 to 450 meters in length when first formed. The largest ones may exceed 120 meters in height and several miles in length. The tabular bergs of Antarctica average 30 to 40 meters in height, but their horizontal dimensions greatly surpass those bergs of the Northern Hemisphere. For example, one iceberg observed near Scott Island in 1956 measured 60 miles by 208 miles.

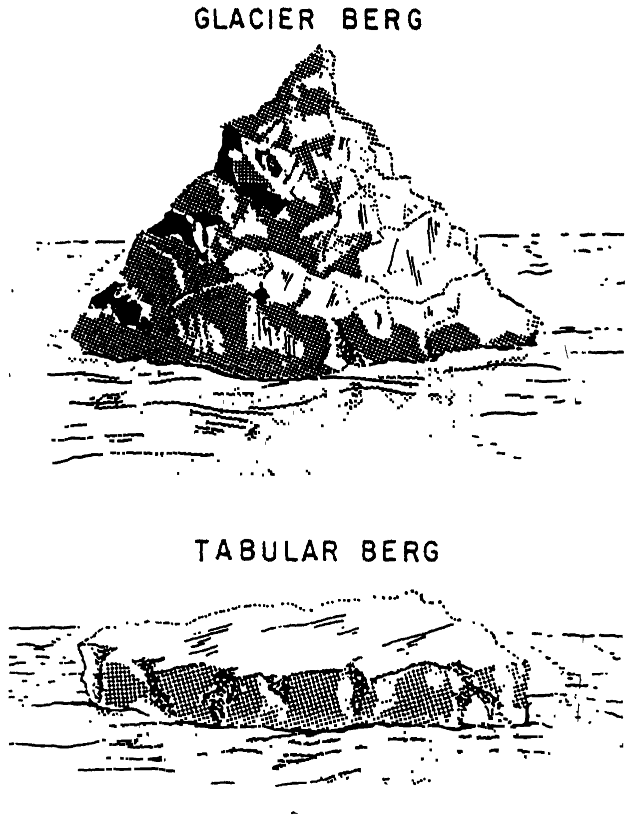

Figure 1-1-7.—Types of icebergs.

The portion of an iceberg that is visible above the water is dependent upon the type of the berg and the density differences between the seawater and the ice. The type of berg (pinnacle or tabular) determines the height of the ice above the water. In the case of the tabular berg, the depth below the surface is about seven times the height above the water line. In the case of the pinnacle or irregular berg, the depth below the surface averages about five times that above the water line.

With regard to density, seawater with a temperature of $-1\,°C$ and a salinity of 35 ‰ produces a density condition that allows for nearly 90 percent of the ice to be submerged.

Irregular icebergs often have rams (protrusions of ice beneath the surface). These rams can be a

great hazard to vessels that might pass close by these type bergs.

Drift.—While the general direction of the drift of icebergs over a long period of time is known, it may not be possible to predict the drift of an individual berg at a given place and time, for bergs lying close together have been observed to move in different directions. The reason for this is that icebergs move under the influence of the prevailing current at the iceberg's submerged depth. This subsurface current often opposes the existing wind and sea or surface drift.

BERGY BITS AND GROWLERS.—Like icebergs, bergy bits and growlers originate from glaciers and form when icebergs and other masses of land ice disintegrate. A bergy bit is a medium sized fragment of glacier ice and is about the size of a small cottage. A growler is a small fragment of ice about the size of a grand piano. It is usually of glacial origin, and generally greenish in color.

SUMMARY

The surface of the sea varies much like that of the land. It can be smooth, rough or ice covered. Its state is governed to a great extent by the atmosphere with which it interfaces. The wind is the primary controller of the sea state (wave action) and the circulation pattern within the oceans (the major ocean currents). The air and seawater temperature differences control the evaporation and condensation processes, while the air temperatures control the formation of sea ice to a large extent.

UNIT 1—LESSON 2

THE OCEAN BODY

OVERVIEW	OUTLINE
Recognize the various properties of seawater and the importance of each.	Properties of seawater
Identify the three layers that make up the three-layer ocean model.	The three-layer ocean
Define mixed layer, main thermocline, and deep layer.	
Differentiate between water masses.	Water masses and water types
Recognize how the deep-ocean circulation differs from the surface circulation and how the circulation is maintained.	Deep-ocean circulation

THE OCEAN BODY

Just as the air of one region of Earth can differ in its makeup from that of another region, so can seawater. For example, the water around Antarctica differs from that of the mid-latitudes and the tropics, and water found at the ocean surface differs from that found at or near the bottom. The differences found in seawater are related to seawater properties. It is the seawater properties that are used to classify water masses. In this lesson, we will cover various seawater properties, the three-layer ocean model as it relates to the property of temperature, and the water masses of the world's oceans.

Learning Objective: Identify the three most important properties of seawater, as well as some of the more common and lesser known properties.

PROPERTIES OF SEAWATER

Temperature, pressure, and salinity are the three most important properties of seawater, and they determine the other physical properties associated with seawater. This differs from pure water, where only pressure and temperature determine the physical properties. Wave motion and the presence of small suspended particles in seawater are also important variables that affect the properties of seawater. Wave motion causes a change in the processes of chemical diffusion, heat conduction, and transfer of momentum from one layer to another. The suspended particles increase the scattering of radiation, thereby absorbing more radiation than a similar layer (thickness) of pure water. The variables of wave motion and suspended particles, although important, cannot be measured.

In addition to temperature, pressure, and salinity, other common physical properties of seawater are water color, transparency, ice (which we've already covered in our discussion of the surface), and sound velocity. Some of the lesser known properties include specific heat, compressibility, osmotic pressure, eddy viscosity, electrical conductivity, radioactivity, and surface tension. Many of the lesser known properties can only be determined using complex mathematical calculation and formulation that incorporates

data on one or more of the common physical properties, especially temperature, pressure, and/or salinity.

Learning Objective: Identify the oceans' heat source, the total and diurnal range of ocean temperatures, the factors that control the distribution of heat in the oceans, and the oceans' vertical-temperature profile.

Temperature

The ocean, like the atmosphere, is heated by the Sun's incoming radiation. In all latitudes the ice-free portions of oceans receive a surplus of radiation. Some of this heat is given up to the atmosphere, and some of it is retained. Because the sea retains a portion of this heat, the sea-surface temperature is normally higher than the air temperature. However this is true only when average conditions are considered. Whether the sea-surface is warmer or colder than the air above it at any particular moment in time is dependent upon the locality, the season of the year, the character of the atmospheric circulation and the character of the ocean currents.

The temperature of the ocean ranges from about $-2\,°C$ to $30\,°C$. Ocean water that is nearly surrounded by land may have higher temperatures, but the open sea, where the water is free to move about, hardly ever heats above $30\,°C$. Here, the ocean currents distribute the heat and tend to equalize the temperature. Deep and bottom water temperatures are always low, varying between $4\,°C$ and $1\,°C$.

The annual variation of sea-surface temperature in any region depends upon the variation of incoming radiation, the character of the ocean currents, and the character of the atmospheric circulation. The annual range of surface temperature is much greater over the oceans of the Northern Hemisphere than those of the Southern Hemisphere. This wider range of temperatures appears to be associated with the character of the prevailing winds, particularly the cold winds blowing from the continents. On the other hand, the annual range of ocean temperatures in the Southern Hemisphere is most definitely related to the range of incoming solar radiation, because of the absence of large land masses south of 45 °S. Here, the prevailing winds travel almost entirely over water. This brings about a far greater degree of consistency in the annual sea-surface temperature patterns and a much smaller annual temperature range compared to the Northern Hemisphere.

The temperatures near the equator experience a semiannual variation. This corresponds to the twice yearly passage of the Sun's most direct rays across the equator.

Sea-surface temperatures change from day to night just like those of the atmosphere, but to a much lesser degree. The diurnal variation of sea-surface temperature in the open ocean is on the average only $0.2\,°C$ to $0.3\,°C$. The greatest diurnal variation takes place in the tropics, with lesser variation at higher latitudes. The range of diurnal variation is dependent on the amount of cloudiness and the direction and speed of the wind.

The annual variation of temperature in subsurface layers depends on several additional factors—namely, the variation in the amount of heat that is directly absorbed at different depths, the effect of heat conduction, the variation in currents related to lateral displacement, and the effect of vertical motion. Diurnal temperature variations in subsurface layers are largely unknown. What we do know is that they are extremely small.

VERTICAL-TEMPERATURE STRUCTURE.—The basic vertical temperature structure of the ocean in its simplest form is best described using the three-layered ocean model, which we will discuss following this section on seawater properties. Generally, there is little temperature change with depth through an upper or mixed layer, a sharp temperature decrease through a main thermocline layer, and a return to a gradual decrease in temperature through a deep water layer.

Learning Objective: Define *salinity*; recognize its effect on seawater density; state its ranges in the open ocean and the major factor that controls it.

Salinity

The term *salinity* is related often to the amount of salt in the water. In oceanography, salinity is defined as "the total amount of dissolved solids in seawater." Salinity is measured in

parts per thousand by weight, and is symbolized ‰. The measurement gives us the grams of dissolved material per kilogram of seawater.

The salinity values of ocean water range between 33 ‰ and 37 ‰, with an average of 35 ‰. In the open ocean, surface salinity is decreased by precipitation, increased by evaporation, and changed by the vertical mixing and inflow of adjacent water. Near shore, salinity is generally reduced by river discharge and freshwater runoff from land. In the colder waters that freeze and thaw, salinity generally increases during periods of ice formation and decreases during periods of ice melt.

Latitudinally, surface salinity varies in a similar manner in all oceans. Maximum salinity values occur between 20° and 23° north and south, whereas minimum salinity values occur near the equator and toward higher latitudes. The controlling factor in average surface salinity distribution is the latitudinal differences in evaporation and precipitation. Exceptions to this statement do occur, and local variations should be expected, especially near the mouth of the larger river systems and in the Atlantic coastal water of the United States, Labrador, Spain, and Scandinavia. The best known region of strong horizontal salinity gradients is the Grand Banks region, where warm, saline Gulf Stream water mixes with the colder, less saline water of the Labrador Current. Here, water with a salinity value as low as 32 ‰ may possibly override or lie adjacent to water having a salinity value greater than 36 ‰. A similar situation prevails in the Pacific Ocean, where the Kuroshio and Oyashio currents mix.

At latitudes poleward of 40° north and south, where precipitation generally exceeds evaporation, salinity values tend to increase with depth. Usually during summer, these positive salinity gradients are accompanied by strong negative temperature gradients and result in very stable water, especially in the coastal regions. These strong, shallow salinity (and temperature) gradients persist through the summer.

Learning Objective: Identify the function and properties of seawater that control pressure, and the unit used to measure pressure.

Pressure

Pressure beneath the sea surface is measured in decibars. The pressure exerted by 1 meter of seawater very nearly equals 1 decibar (1/10 of a bar) or 100,000 dynes per square centimeter.

The farther one descends in the sea, the greater the pressure, and since pressure in the ocean is essentially a function of depth, the numerical value of pressure in decibars approximates the ocean depth in meters. Therefore, pressure ranges from zero at the surface to over 10,000 decibars in the deepest parts of the oceans. The pressure is created by the weight of the seawater above. The weight per unit volume of seawater, in turn, varies with the temperature and salinity. In a column of water of constant depth, the pressure increases as the temperature of the sea decreases, or the salinity increases, or both.

Learning Objective: Define *density*. Identify those properties of seawater that density is dependent on. Recognize how density effects seawater stability.

Density

The density of seawater is dependent on salinity, temperature, and pressure. At constant temperature and pressure, density varies with salinity. A temperature of 32°F and an atmospheric pressure of 1,013.2 mb are considered standard for density determination. At other temperatures and pressures the effects of thermal expansion and compressibility are used to determine density. The density at a particular pressure affects the buoyancy of various objects, notably submarines. Density is defined as mass per unit volume, and is expressed in grams per cubic centimeter.

The greatest changes in density of seawater occur at the surface. Here, density is decreased by precipitation, runoff from land, melting of ice, or heating. When the surface water becomes less dense, it tends to float on top of the more dense water below. There is little tendency for the water to mix; therefore, the condition is one of stability. The density of surface water is increased by evaporation, the formation of sea ice, and cooling. If the surface water becomes more dense than the water below, it sinks to a level having the same density. Here, it tends to spread out to form a layer, or to increase the thickness of the layer of which it has become a part. As the more dense water sinks, the

less dense water rises, and a convective circulation is established. The circulation continues until the density becomes uniform from the surface to a depth at which a greater density occurs. If the surface water becomes sufficiently dense, it sinks all the way to the bottom. If this occurs in an area where horizontal flow is unobstructed, the water that has descended spreads to other regions, creating a dense bottom layer. Since the greatest increase in density occurs in polar regions, where the air is cold and great quantities of ice form, the cold, dense polar water sinks to the bottom and then spreads to lower latitudes. This process has continued for such a long period of time that the entire ocean floor is covered with this dense polar water. This explains the layer of cold water at great depths in the ocean.

Learning Objective: Recognize the degree to which seawater is compressible, and the importance of this property.

Compressibility

Seawater is nearly incompressible, its coefficient of compressibility being only 0.000046 per bar under standard conditions. This value changes slightly with changes in temperature or salinity. The effect of compression is to force the molecules of the substance closer together, causing the substance to become more dense. Even though the compressibility of seawater is low, the total effect is considerable because of the amount of water involved. If it were zero, sea level would be about 90 feet higher than it is now.

Learning Objective: Define *viscosity*, and recognize the other properties of seawater that control it.

Viscosity

Viscosity is resistance to flow. Seawater is slightly more viscous than freshwater, and the level of resistance is controlled by its temperature and salinity. Viscosity increases when salinity increases or the water temperature decreases. However, the effect of decreasing temperature is greater than that of increasing salinity. The resistance rate is not uni.orm; it increases as the temperature decreases. Because of the effect of temperature on viscosity, an incompressible object might sink at a faster rate in warm surface water than in colder subsurface water. For most compressible objects, viscosity effects may be more than offset by the compressibility of the object. In reality this is a very simple explanation to a complex problem, since the actual relationships existing in the ocean are considerably more complicated than portrayed here.

Learning Objective: Define *specific heat* and recognize the effect salinity has on the specific heat of seawater.

Specific Heat

In oceanography, specific heat is the number of calories needed to raise the temperature of 1 gram of seawater 1 °C. The specific heat of seawater decreases slightly as salinity increases.

Land heats and cools much more rapidly than seawater, its specific heat being much less than that of seawater. This, in part, accounts for the land having a much greater temperature range than the sea, which results in monsoons and the familiar land and sea breezes of tropical and temperate regions.

The ratio of specific heat to seawater at a constant pressure and constant volume has a direct relationship to the speed of sound in water.

Learning Objective: Recognize the effects temperature, pressure, and salinity have on the thermal expansion of seawater, and identify one of the major roles of thermal expansion in the sea.

Thermal Expansion

Liquids expand and contract when temperature changes take place; some more than

others. Seawater has a higher coefficient of expansion than that of freshwater. Within the sea, the coefficient of thermal expansion is effected by salinity, temperature, and pressure. It is greater in high salinity water; greater in warm water than in cold (under similar salinity conditions); and it increases with increasing depth under constant temperature and salinity conditions. Of course, constancy is not a trademark of any of these properties; they are all quite variable. In turn, the thermal expansion that takes place in the sea varies and is difficult to assess.

A major role of thermal expansion is in the formation of ice. PURE WATER is most dense at 4 °C. Thermal expansion takes place when water warms above 4 °C, but it also expands when it cools below 4 °C. When expansion takes place, the volume is increased, which in turn decreases the density. When water cools below 4 °C, it expands slightly, and as it freezes, it expands much more. If water failed to expand during the freezing process, the density of ice would be such that it would sink to the bottom on forming. In the cold of winter, freshwater lakes would eventually become solid blocks of ice. Come summer, only the upper few feet of ice would melt, leaving the remaining ice beneath the melted water.

Learning Objective: Identify the properties that control sound velocity in the ocean and recognize how each controls the speed and direction of a sound wave.

Sound Velocity

If you remember from an earlier lesson, velocity takes into account both speed and direction. The speed of sound in seawater is governed by temperature, pressure, and salinity. An increase in temperature increases the speed of sound in water, while a decrease in temperature decreases the speed of sound. The same relationship applies to pressure and salinity. An increase in pressure causes an increase in sound speed, as does an increase in salinity, and vice versa.

Since pressure is a function of depth in the sea, if we were to discount the effect of temperature and salinity, sound would travel faster at the ocean bottom than it does at the surface. However, we cannot discount either of these other two variables, especially temperature. It is the most important property controlling the speed of sound in water.

As far as direction is concerned, sound waves travel in straight lines only in a medium in which the speed is everywhere constant. For this to occur in seawater, the temperature, pressure, and salinity values would have to be unchanging. Changes in any or all of these variables do occur, which in turn affects the speed of sound waves. The change in speeds along the sound wave causes the wave to change direction. Sound waves are bent (refracted) in the direction of the slower sound velocities. The degree of refraction is proportional to the velocity gradient. If the velocity gradient is such that there is a rapid increase in the speed of sound with depth, a sound wave will be sharply refracted toward the surface, the direction of the slower sound velocities. On the other hand, a rapid decrease in the speed of sound with depth causes a sound wave to be sharply refracted toward the ocean bottom. Sound in the ocean, especially as it relates to anti-submarine warfare, will be covered in greater detail in Unit 2.

Learning Objective: Identify the three layers of the three-layered ocean model and differentiate between mechanical and convective mixing.

THE THREE-LAYERED OCEAN

A convenient method of visualizing the sea is to divide it into layers in much the same way that we do the atmosphere. Using bathythermograph information (temperature versus depth profiles), the oceans display a basic three-layered structure: the mixed layer, main thermocline, and deep water layer. The latitudinal distribution of these layers is shown in figure 1-2-1, while the typical

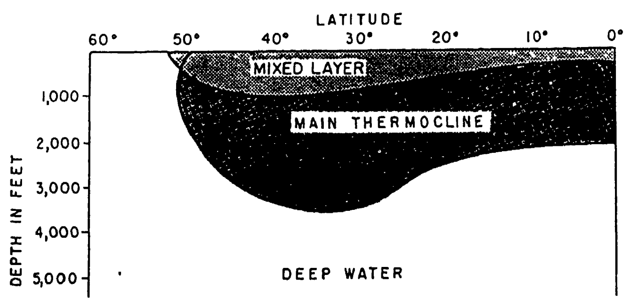

Figure 1-2-1.—North-south distribution of a simple three-layered ocean (North Atlantic) in winter.

thermal structure is shown in figure 1-2-2. Both figures are representative of winter.

Mixed Layer

The mixed layer is the upper layer of the three-layered ocean model. It is a layer of fairly constant warm temperatures which, in middle latitudes, extends from the surface to a maximum depth of about 450 meters, or 1,500 feet. This layer gets its name from the mixing processes that bring about its fairly constant warm temperatures. The two mixing processes are classified as mechanical and convective.

MECHANICAL MIXING.—This mixing process is caused by wave action, surface storms, etc. The wave action stirs up the water. Warmer surface water is driven downward, where it mixes with colder subsurface water. Eventually, a layer of water with a fairly constant temperature is produced. This process is more important in summer than in winter, because surface waters are much warmer and less dense than subsurface waters, thereby producing a stable water column. The mechanical mixing process is more rapid and irregular than the convective mixing process.

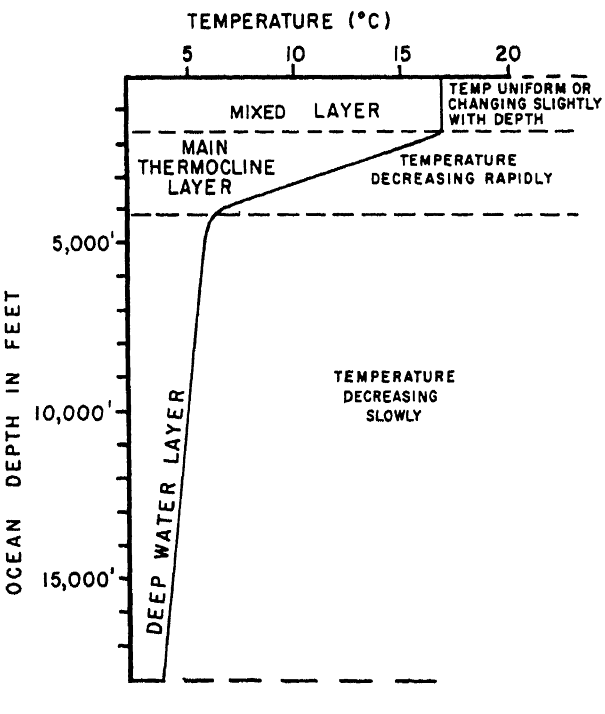

Figure 1-2-2.—Typical thermal structure of the oceans (winter conditions in mid-latitudes).

CONVECTIVE MIXING.—This process occurs as a result of changes in water stability. When surface waters become more dense than subsurface waters, an unstable condition exists. Such a condition can occur when there is an increase in surface salinity owing to evaporation or the formation of ice, or by a decrease in the surface water temperature. A temperature decrease of .01 °C or a salinity increase of 0.01 ‰, is sufficient to initiate the convective mixing process. In the former case, for example, a cold polar or arctic air mass moving over warm water cools the surface water before it can cool the subsurface water. As the surface waters cool and become colder than the subsurface waters, they become more dense and sink. As the colder surface water sinks, the warmer and less dense subsurface water rises to the surface to replace it. This process continues until the water is thoroughly mixed, the density difference eliminated, and the water column stabilized.

Even though winds and the resultant wave action are generally stronger during winter, convective mixing, caused by the colder winter air temperatures, produces a deeper mixed layer than can be attained by mechanical mixing. It is for this reason that convective mixing is considered the more important of the two, and the predominant process of winter.

The convection process is strongest in northern waters where vertical temperature and salinity gradients are not extreme and surface waters undergo a high degree of cooling. Convective mixing attributed to salinity changes is most noticeable in the Mediterranean and Red seas, where evaporation far exceeds precipitation.

We have looked at both processes individually; however, the two processes can and often do take place simultaneously. When this occurs, the mixed layer normally attains a greater depth than would be attained by either process individually.

Main Thermocline

The main thermocline is the central layer of the ocean. It is found at the base of the mixed layer and is marked by a rapid decrease of water temperature with depth.

SEASONAL THERMOCLINE.—At high latitudes there is no marked change in water temperature with the seasons, while in the mid-latitudes, a seasonal thermocline develops with the approach of summer. This seasonal thermocline comes about from the gradual warming of the

surface waters. The warming takes place in the upper few hundred feet of the surface, and results in the seasonal thermocline becoming superimposed on the main thermocline. Figure 1-2-3 illustrates the development of the seasonal thermocline in the mid-latitudes.

The mid-latitude summer thermocline is more pronounced than the thermocline of spring or autumn. Bathythermograph traces of the summer thermocline show that it affects a much broader range of depth than at any other time of year. In our illustration, the seasonal thermocline is roughly 35 meters thick (90 to 125 meters deep). Note, also, that the winter temperature profile shows no seasonal thermocline. The mixed layer extends to a depth in excess of 160 meters. Come spring, the surface water is warmed and a seasonal thermocline develops between 35 and 60 meters. As summer takes hold, the water warms to 25 °C and the mixed layer extends to a depth of approximately 90 meters. The thermocline now exists between 90 and 125 meters. In summer, the seasonal thermocline is deeper and covers a broader range of depth than at any other season of the year.

With the approach of autumn, the mixed layer continues to drive the thermocline deeper, but the water within the mixed layer is cooler than it was in summer. Just as in the spring, the cooler water in the mixed layer decreases the range of depths covered by the thermocline. In low latitudes, small seasonal temperature changes make it difficult to distinguish between the seasonal and the permanent thermoclines.

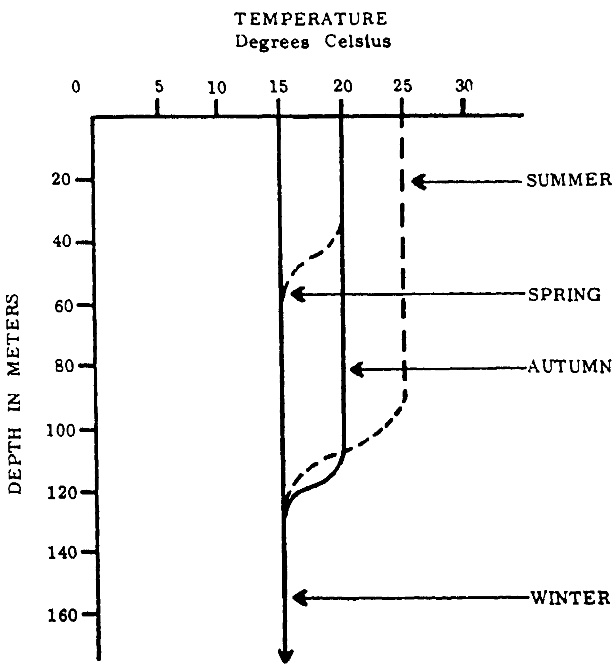

Figure 1-2-3.—Upper level thermal structure of seasonal thermocline in middle latitudes.

Deep Water Layer

The deep water layer is the bottom layer of water, which in the middle latitudes exists below 1,200 meters. This layer is characterized by fairly constant cold temperatures, generally less than 4 °C.

To better understand the basic vertical temperature distribution, look once again at figure 1-2-1. At high latitudes in winter, the water is cold from top to bottom. The vertical temperature profile is essentially isothermal (no change in temperature with depth). In middle latitudes, the structure is like that illustrated in figure 1-2-2. In low latitudes, the mixed layer extends to a depth of about 300 feet. Here, the main thermocline is encountered and the temperature drops about 8 °C more than it does in the mid-latitudes. This sharper drop is due to the higher surface temperature in the lower latitudes. The thermocline extends to 2,100 feet, where the deep layer is encountered.

Learning Objective: Define *water mass* and *water type* and identify the properties used in their classification; recognize the oceans' basic vertical structure with regard to their latitudinal distribution; and recognize their source regions and how they are formed.

WATER MASSES AND WATER TYPES

The concept of visualizing water masses as we do air masses is possible because both are based on the physical properties that go into their makeup. The properties of temperature and salinity are used to classify both water types and water masses.

A water type has a single value of salinity and a single value of temperature associated with it, while a water mass takes into account a range of temperatures and salinities. For example, Red Sea water is a water type characterized by a

temperature of 9 °C and a salinity of 35.5 ‰. On the other hand, North Atlantic Central Water (a water mass) is characterized by a range of temperatures (4 °C to 17 °C) and salinity (35.1 ‰ to 36.2 ‰). A water mass may be considered to be made up of a combination of two or more water types.

Formation

The vast majority of water masses are formed at the surface of the sea in middle and high latitudes. Cold, highly dense surface water sinks until it reaches a level having the same constant density. Here, it spreads out horizontally. The manner in which it spreads out depends on its density in relation to the density of the surrounding water. This is true of nearly all water masses, except those of low latitudes—in particular, the equatorial water masses of the Indian and Pacific Oceans. These water masses are formed by the mixing of subsurface waters.

Distribution

In low and middle latitudes the vertical arrangement of water is such that we can distinguish a surface layer, upper water (central and equatorial), intermediate water, deep water, and in some localities, bottom water. In high latitudes, the layered structure all but disappears because the surface water is similar to the water at or near the bottom.

SURFACE LAYER.—The surface layer is not classified as a water mass or water type, because its properties vary widely from one area to another, depending on current variations, evaporation, precipitation, and various seasonal changes, especially in the middle latitudes. In low and middle latitudes it is found above central and/or equatorial water to depths of 100 to 200 meters. The surface layer is separated from deeper water by a transition layer (the main thermocline).

Beneath the surface layer, we encounter the water types and water masses. Like air masses, the water types and water masses have source regions in which they form. Figure 1-2-4 is provided as a reference for the source regions of various water types and water masses.

CENTRAL WATER MASSES.—Central water is normally found in relatively low latitudes although its source region is in the region of the subtropical convergences (between the 35th and 40th parallels in each hemisphere). Convergences are regions in the ocean where surface waters are brought together by the currents. In the western North Atlantic Ocean, a region of subtropical convergence exists where the Gulf Stream meets the colder, more dense Labrador current. Convergences are marked by rapidly rising sea-surface temperatures.

Central water is not usually discernible at the surface and is generally relatively shallow. Its greatest thickness is observed along its western boundaries. In the western North Atlantic in the region of the Sargasso Sea, the thickness may reach 900 meters.

Variations in heating and cooling, evaporation and precipitation, ocean circulation patterns, and mixing processes all contribute to the salinity values of central water being either quite similar or considerably different. For example, central water of the South Atlantic Ocean, the Indian Ocean, and the western South Pacific Ocean all have similar salinity values, while the salinity values of North Atlantic central water are considerably higher than the central water of the North Pacific Ocean.

You will note as you look at figure 1-2-4 that the central water of the North and South Atlantic oceans is not separated by equatorial water like the central water of the North and South Pacific oceans. Instead, the central water of the North and South Atlantic come together and mix, forming a region of transition consisting of intermediate properties.

EQUATORIAL WATER MASSES.—Equatorial water is found in the Pacific and in the Indian Ocean. In the Pacific it is thought to originate on the southern side of the equator. There are two reasons for this: Its properties are similar to those of the water masses of the South Pacific, and its salinity values are higher than those of the water masses found in the North Pacific Ocean.

Equatorial water is also found in the northern part of the Indian Ocean. Here, its higher salinities are probably due to its mixing with the waters of the Red Sea. However, this conclusion has not been substantiated.

Equatorial water, like central water, is not discernible at the surface, because the temperature and salinity values used to isolate it cannot be clearly ascertained in the upper 100 to 200 meters.

INTERMEDIATE WATER.—Intermediate water is found below central water in all oceans.

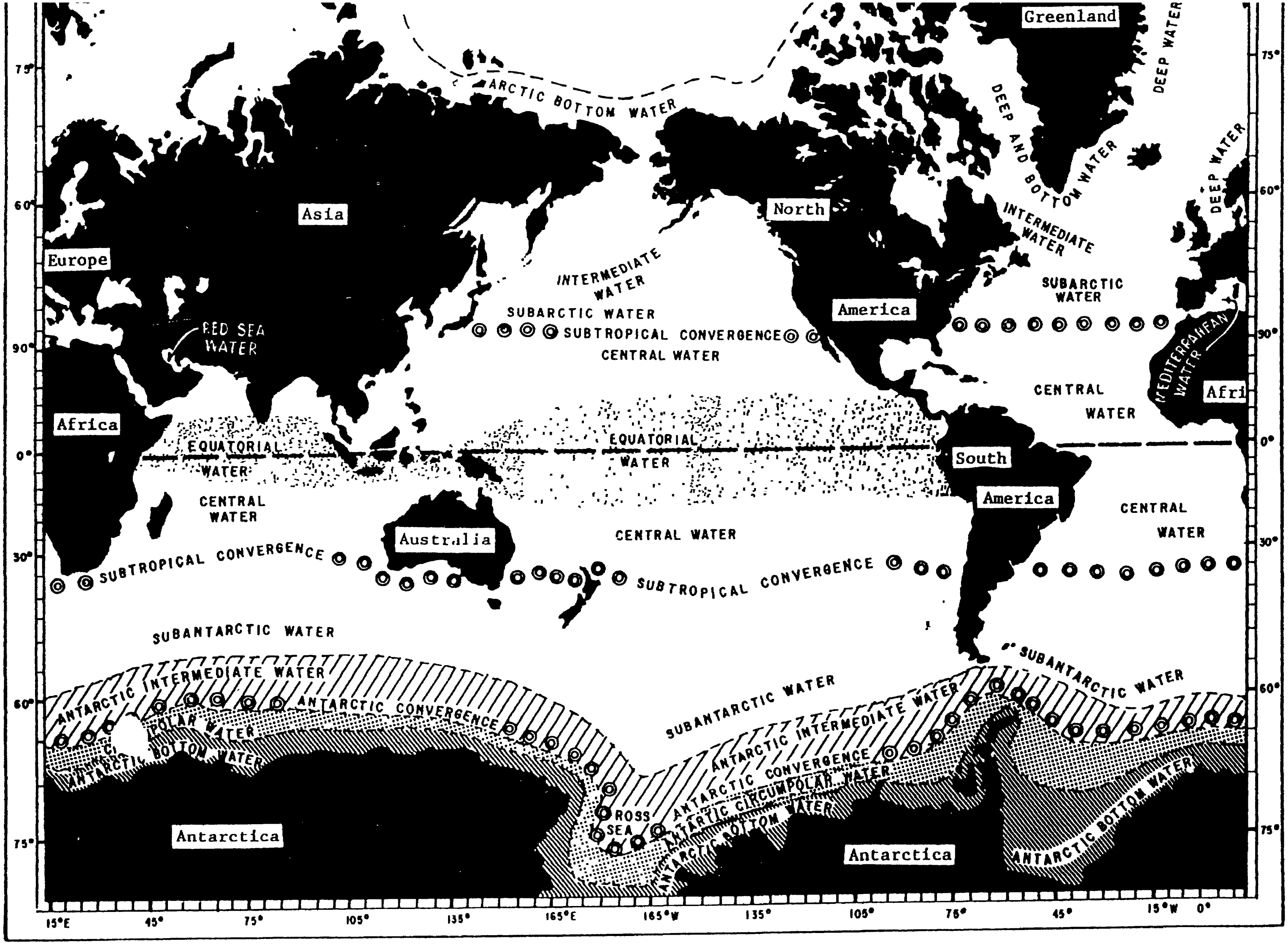

Figure 1-2-4.—Approximate source regions for water masses of the world.

Intermediate water includes Antarctic intermediate water, Arctic intermediate water, Mediterranean water, and Red Sea water.

Antarctic Intermediate Water.—Antarctic intermediate water encircles the Antarctic continent and is the most widespread of all the intermediate water masses. It forms in the vicinity of the Antarctic convergence, where it sinks. As it sinks, it flows north and mixes with the water masses that lie immediately above and below it.

In the Atlantic, the absence of equatorial water allows Antarctic intermediate water to flow across the equator and reach roughly 20°N to 35°N latitude. In the South Pacific and Indian oceans, where equatorial water does exist, Antarctic intermediate water fails to reach the equator. It spreads north to about 10°S latitude.

One of the characteristics of Antarctic intermediate water is its low salinity (34.1 ‰ to 34.6 ‰). In comparison to the water around it, it displays the lowest salinity values.

Arctic Intermediate Water.—Arctic intermediate water and sub-Arctic water are similar; however, in the North Atlantic Ocean, Arctic intermediate water forms only in small quantities, and in a relatively small area east of the Grand Banks of Newfoundland.

In the North Pacific, Arctic intermediate water forms during winter at the convergence formed by the Oyashio current and the Kuroshio Extension. It exists between latitude 20°N and 43°N, except off the west coast of North America. Here, sub-Arctic water extends to lower latitudes, and the northern boundary of the intermediate water is pushed much farther south.

Mediterranean Water.—This water mass is formed by the interaction of dense Mediterranean Sea water with waters of the adjacent North Atlantic Ocean. The more dense Mediterranean water flows out through the Strait of Gibraltar and sinks to a depth of about 1,000 meters, where it mixes with the water at this depth.

Red Sea Water.—This water type is found over large parts of the equatorial and western regions of the Indian Ocean. Large quantities of warm, highly saline water from the Red Sea flow into the Indian Ocean, where its mixes with Antarctic intermediate water to form the Red Sea water mass. The spreading of Red Sea water is not as well-defined as Mediterranean water.

ANTARCTIC CIRCUMPOLAR OR SUB-ANTARCTIC WATER.—This water mass is thought to form through a combination of mixing and vertical circulation in the region between the subtropical and Antarctic convergences. Here, large quantities of Antarctic intermediate water and Antarctic bottom water mix with North Atlantic deep water to form Antarctic circumpolar water.

The physical properties of this water mass are quite conservative, and as its name implies, it extends completely around the Antarctic continent and the South Pole. Because Antarctic circumpolar water forms in the deeper waters of the Antarctic Ocean, it is often referred to as sub-Antarctic water.

SUB-ARCTIC WATER MASSES.—Sub-arctic water is much like Antarctic circumpolar or sub-Antarctic water; however, there are differences. The differences are attributed to the land and sea distribution in the two hemispheres. In the Southern Hemisphere, the Antarctic convergence extends around the continent of Antarctica, but in the Northern Hemisphere, the Arctic convergence is found only in the western portions of oceans. However, even in these areas the convergence is not always well-defined.

In the North Atlantic Ocean, sub-Arctic water covers a relatively small area, and it possesses a higher salinity than surrounding waters. On the other hand, the sub-Arctic water of the North Pacific is much more extensive, and its salinity values are lower than surrounding waters.

DEEP AND BOTTOM WATER MASSES.—In the deep ocean basins below intermediate water, high density deep and bottom water exists. These water masses form in both hemispheres. In the Southern Hemisphere, Antarctic bottom water forms near the Antarctic continent, while in the Northern Hemisphere, Arctic deep and bottom water forms in northwestern Labrador Basin and in a small area off the southeast coast of Greenland. These water masses form at the surface, sink, and spread out to fill the deep-ocean basins. Deep and bottom waters are detectable in areas far removed from their source regions. More information on the spreading of deep and bottom water is presented in the following discussion on deep-ocean circulation.

Learning Objective: Recognize how deep-ocean circulation differs from surface circulation and how the circulation pattern is maintained.

DEEP-OCEAN CIRCULATION

Methods devised to determine deep-ocean circulation have met with varying success, but all point to a quite complex pattern of subsurface currents.

The deep-ocean currents differ from surface currents in that they (1) are density driven, (2) are much slower, (3) move in a predominantly north-south direction, and (4) they cross the equator.

The deep-ocean circulation is often referred to as a thermohaline circulation, because the circulation is controlled by differences in temperature and salinity. Varying combinations of temperature and salinity produce water of varying densities, and it is these density differences that produce the deep-ocean circulation.

Since the majority of the world's water masses are formed at the surface, our discussion of the deep-ocean circulation must start here. We will move through the circulatory pattern, beginning and ending with the surface waters around Antarctica.

As the high density surface water around Antarctica sinks, it mixes with the warmer, more saline circumpolar water to form Antarctic bottom water. See figure 1-2-5. Because Antarctic bottom water is the most dense water found in the ocean, it sinks to the ocean floor and spreads, or flows, northward into the deep-ocean basins of the Atlantic, Pacific, and Indian Oceans. This water mass has been tracked as far north as the 35th parallel of the Northern Hemisphere.

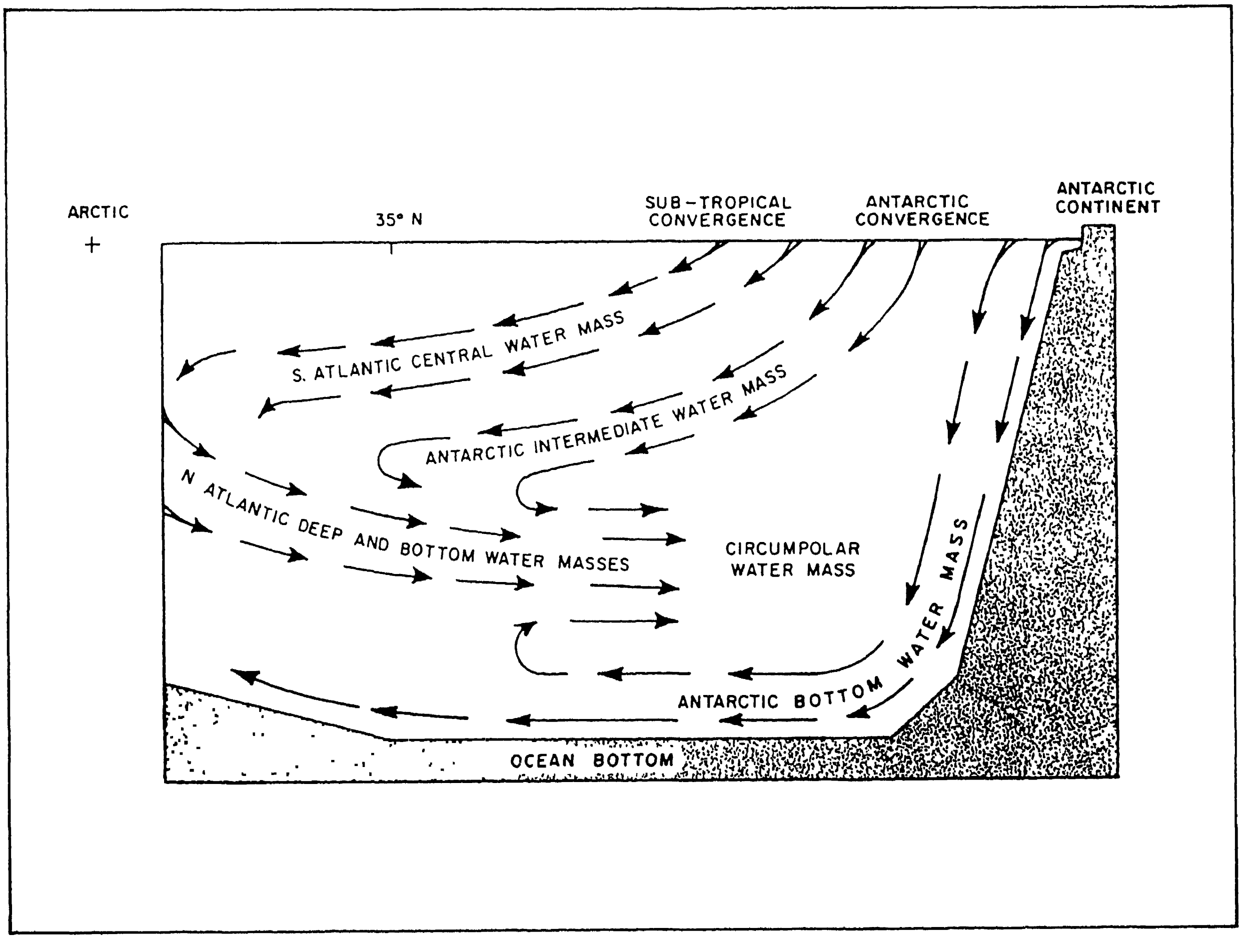

Figure 1-2-5.—Typical flow pattern of circulation within the ocean.

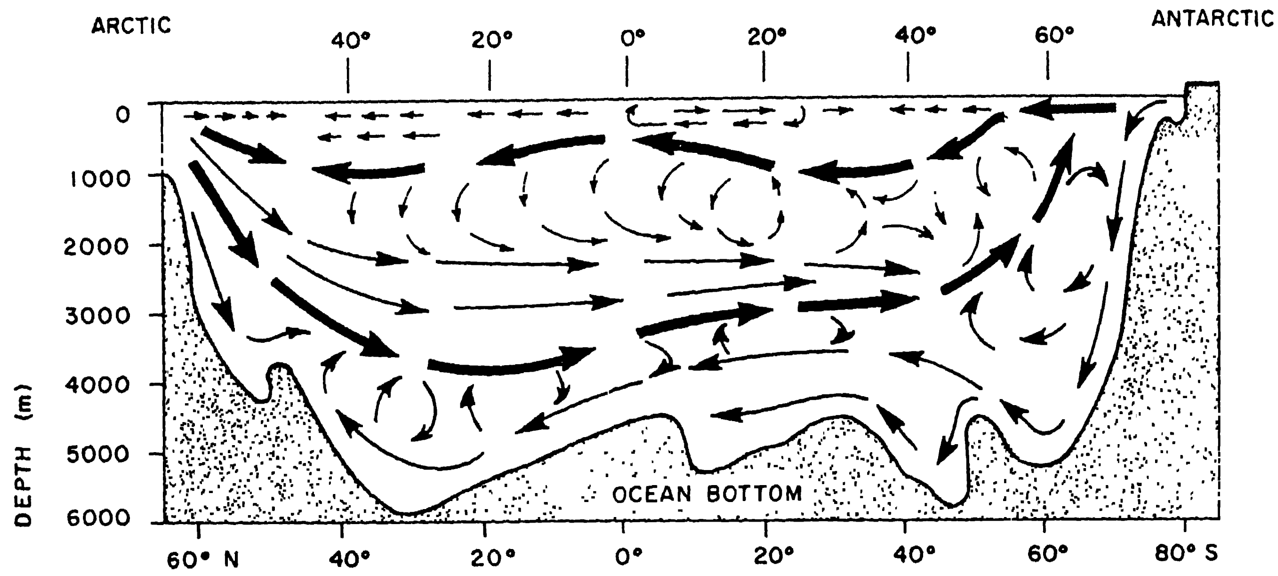

Figure 1-2-6.—Simplified general circulation pattern of the Atlantic Ocean.

In the sub-Arctic regions of the Northern Hemisphere, the same type of process occurs. The cold, dense surface water sinks and forms North Atlantic deep and bottom water. This water mass spreads southward and is in contact with the bottom, except where it encounters Antarctic bottom water. (See figure 1-2-6.) Being less dense than Antarctic bottom water, it is found above Antarctic bottom water wherever the two exist together.

The North Atlantic deep and bottom water eventually makes its way back to the Antarctic Ocean, where it mixes with intermediate water masses and Antarctic bottom water to form Antarctic circumpolar water. Here, the cycle begins again as the cold, dense surface water of Antarctica sinks and mixes with the circumpolar water.

Above the deep and bottom waters, the intermediate water masses also show a basic equatorward movement. Antarctic intermediate water actually crosses the equator and moves as far north as 20° to 35°N. Its Northern Hemisphere counterpart, Arctic intermediate water, moves south but does not cross the equator. Mediterranean and Red Sea water both cross the equator, and have been identified far into the Southern Hemisphere.

The Central and Equatorial water of low and middle latitudes move poleward in their respective hemispheres, while in high latitudes the near-surface waters move toward the equator.

The Atlantic circulation is considered much more vigorous than that of the Pacific, because surface-density contrasts are much greater. However, even with the greater surface-density contrasts, the circulation is SLOW—VERY SLOW.

The deep-sea currents associated with the deep-ocean circulation flow at a rate of a few centimeters per second or less. If we were able to free float a bottle at a designated depth, this rate of speed would equate to the bottle moving less than 2 degrees of latitude (120 nmi) in a year, or 0.06 nmi/hr.

In summary, and in its simplest form, we can say that the deep-ocean circulation consists primarily of (1) equatorward-flowing subsurface water, which moves at an extremely slow rate of speed and (2) the much faster poleward-flowing surface water.

UNIT 1—LESSON 3

THE OCEAN FLOOR

OVERVIEW	OUTLINE
Name and describe the five major ocean provinces and the relief features associated with the ocean bottom.	Bottom topography
Name and describe the various types of bottom sediments.	Bottom composition

THE OCEAN FLOOR

In *AG2,* volume 1, reference was made to the fact that Earth's topography (mountains, valleys, etc.) has a definite and important effect on the elements and characteristics of its surrounding atmosphere. The same relationship exists between the ocean floor and the oceans. The irregular terrain of the ocean floor affects the movement of ocean water, temperature gradients in areas of channeling, and in the area of naval operations, submarine and antisubmarine (ASW) tactics. Many relief features and bottom types are used by submariners to conceal their submarines and lessen their chances of being detected by surface sonars. Sonar transmissions that impact the bottom are affected by the bottom topography (smooth, irregular, etc.) and types of bottom (sand, mud, etc.). Sonar performance may be improved or hindered by the bottom; therefore, submariners use the bottom to their best advantage. Submariners make extensive use of bottom contour charts in navigation, and many relief features are used to obtain navigational fixes.

The surface fleet must also be aware of the relief features and bottom types in order to assess the effectiveness of their search sonars.

Learning Objective: Name and describe the five major oceanic provinces and the relief features associated with the ocean bottom.

BOTTOM TOPOGRAPHY

If we were able to walk from the land above sea level to the deepest depths beneath the sea, our walk would be mostly downhill. On leaving the shore, our walk would take us through five major bottom provinces; the continental shelf, the continental slope and rise, the ocean basin, and the mid-ocean ridges. See figure 1-3-1.

Continental Shelf

The continental shelf is the first province we encounter on leaving land. The average width of the shelf is approximately 40 miles, but in some places, there is no shelf (for example, along the west coast of South America). The widest shelf is found along the glaciated coast of Siberia, where it extends out roughly 800 miles. Continental shelves comprise about 7.5 percent of the total ocean bottom.

The shelf has a very gradual slope. It declines at an average rate of 2 fathoms per mile, and at

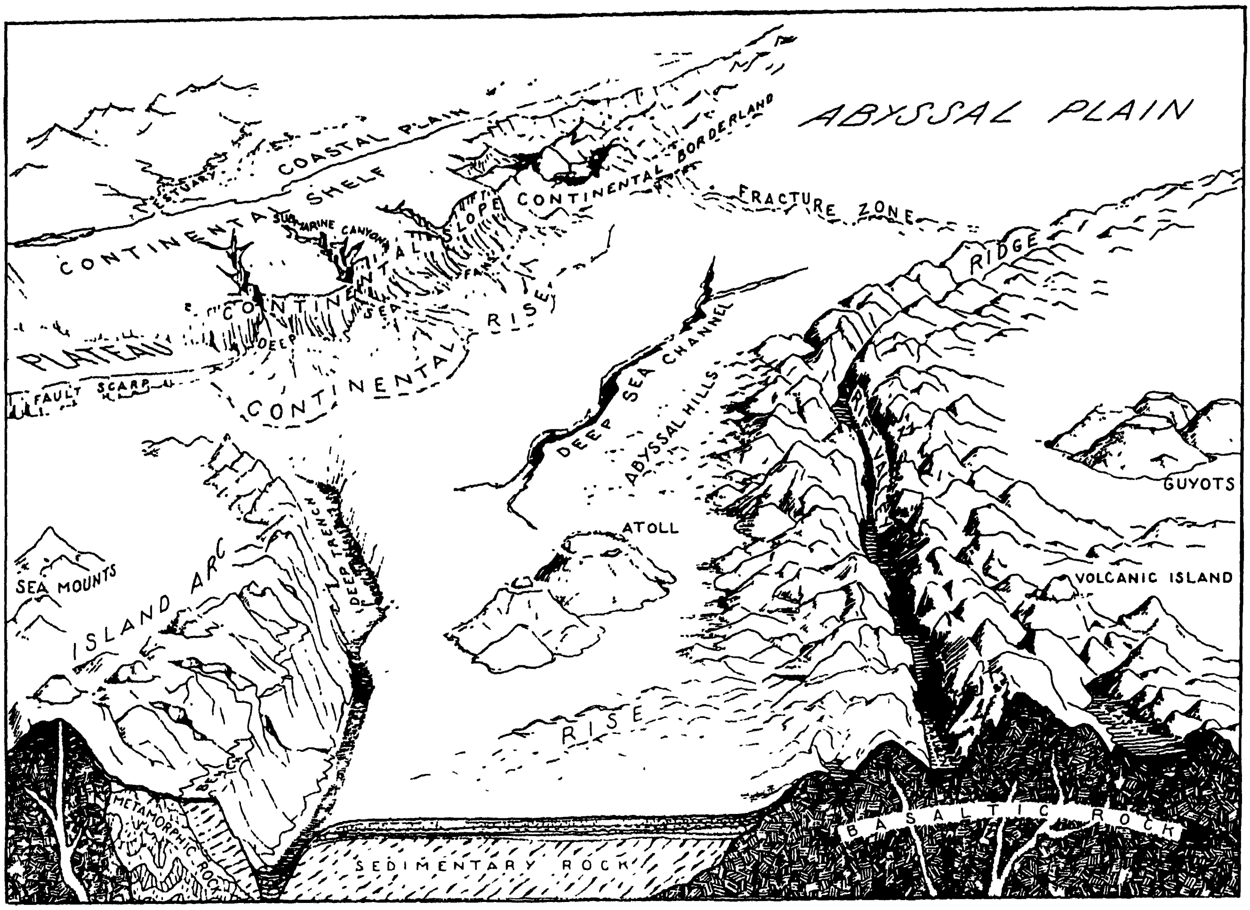

Figure 1-3-1.—The five major bottom provinces.

its seaward limit, the water above the shelf is usually 60 to 100 fathoms deep (1 fathom = 6 feet). Although the average slope of the shelf is gradual, terraces, ridges, hills, depressions, and deep canyons are found within its boundaries.

The shelf region is a transition zone between freshwater runoff from land and the more saline water of the sea; consequently, it is an area of great mixing of water with generally unstable water conditions. Currents normally run parallel to the shore in this region.

Continental Slope

At the seaward edge of the continental shelf the slope becomes much steeper. This region is known as the shelf break. The drop off is rapid. On the average, the slant ratio is roughly 20 times greater than that of the continental shelf. The ratio is generally much greater off mountainous coasts than off wide, well-drained plains. On bottom contour charts (figure 1-3-2), the bottom contours are tightly packed, thereby reflecting the much steeper gradient.

The continental slope resembles a steep cliff that has been eroded by heavy rains. Its most striking features are the submarine canyons, deep cuts or scars, that are prevalent along the slope face. These canyons are thought to have been formed (or cut out) by turbidity currents, which are dense, sediment-laden currents that flow along the ocean floor. Some of these canyons are equal in size to the Grand Canyon. At the seaward end of these canyons, large amounts of sediment are deposited and spread out in a fan-like manner to form the continental rise. Refer to figure 1-3-1 again.

Continental Rise

The continental rise is found seaward of the continental slope, in approximately 500 fathoms of water. It is made up of thick sediment deposits that cover irregular relief features. These deposits slope gently seaward forming the abyssal plains of the deep ocean basins. At the seaward edge of

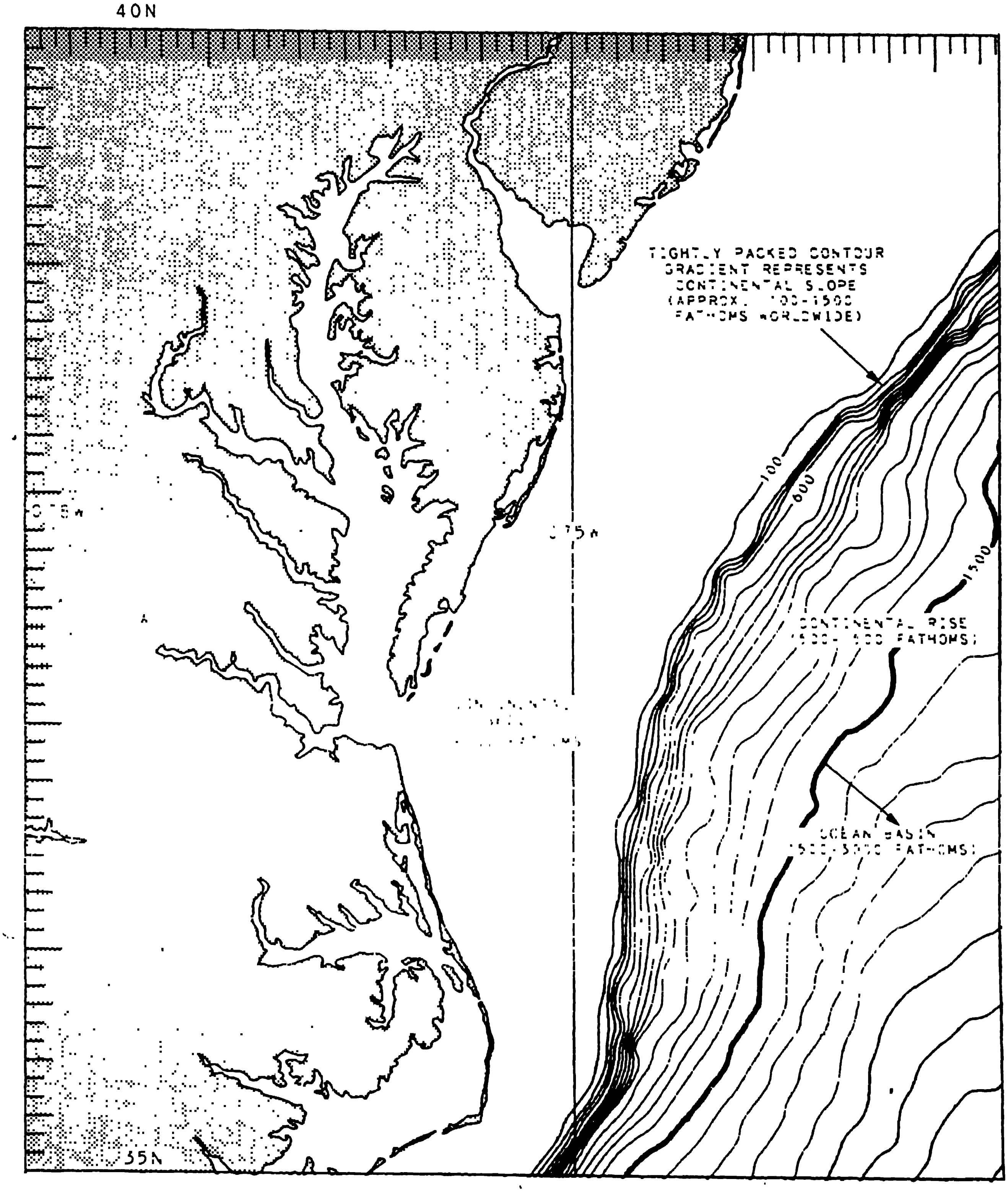

Figure 1-3-2.—Bottom contour chart.

the continental rise, the water depth is about 1,500 fathoms.

Ocean Basin

The ocean basins account for 76 percent of the ocean floor, and their depths range from 1,500 to 3,000 fathoms. They have a very slight average incline of no more than 1:90 miles. For every 90 miles seaward the bottom slopes no more than 1 mile. However, superimposed on this very flat plain are many rugged relief features, such as seamounts, guyots, atolls, sills, and trenches.

SEAMOUNTS.—Seamounts are submerged, isolated, pinnacled mountains rising 3,000 feet or more above the sea floor.

GUYOTS OR TABLEMOUNTS.—Guyots are submerged, isolated, flat-topped mountains that rise 3,000 feet or more above the sea floor.

ATOLLS.—Atolls are seamounts or guyots that have broken the surface, and coral deposits have built up around the rim. The coral forms a reef around a shallow body of water—a lagoon.

VOLCANIC ISLANDS.—These islands occur individually and in groups (island arcs). They are formed by volcanic eruptions. About 10,000 volcanoes dot the ocean floor, and they are especially abundant in the western Pacific basin. The Hawaiian Islands are probably the best known example of volcanic islands. In the North Atlantic Ocean, the most recent volcanic island (Surtsey) was formed south of Iceland along the Mid-Atlantic Ridge in 1964.

SILLS.—Sills are elevated parts of the ocean floor that partially separate ocean basins. A sill restricts the movement of bottom water masses and results in their partial, and in some cases nearly total, isolation.

TRENCHES.—Trenches are long, narrow, and relatively steep-sided depressions. They comprise the deepest portions of the oceans. The trenches of the Pacific Ocean stretch for as long as 2,500 miles (Peru-Chile Trench), are more numerous than in any other ocean, and have by far the greatest depths in the oceans. For example, the Mariana Trench is 35,600 feet deep; the Tonga Trench, 35,430 feet deep; and the Mindanao Trench, 34,428 feet deep. Trenches are normally found on the seaward side of island arcs, while relatively shallow seas exist on the continental side.

Ridges

On leaving the abyssal plains, we come to the last of the oceanic provinces, the mid-ocean ridges. The Mid-Atlantic Ridge is the most conspicuous of all ridges. It extends from Iceland southward across the equator to about 55°S, forming an eastern and western basin in the Atlantic. The Mid-Atlantic Ridge rises from a depth of 2,500 fathoms and is continuous at depths of less than 1,500 fathoms over the greater part of its length. In several places, this ridge rises above sea level to form islands such as the Azores and Ascension.

Learning Objective Name and describe the various types of bottom sediments.

BOTTOM COMPOSITION

Most of the ocean bottom is covered by various types of bottom sediments, deposits of mineral grains and rock fragments from the continents, mixed with dissolved shells and bones of marine organisms. In general, sediment deposits are thin or absent on the newly formed crust of mid-ocean ridges and are thickest on the older crust and near continents. The four major classifications of sediments are terrigenous, pelagic, glacial marine, and volcanic.

Terrigenous Sediments

Terrigenous means "of land origin". Terrigenous sediments are the land derived silts and clays that are carried to sea by rivers. Winds also carry earth (dust) and sand out to sea and deposit them on the surface, where they eventually sink to the bottom. Terrigenous deposits are mostly found in the region of the continental shelf.

Pelagic Sediments

These sediments are also known as ooze. They form in deep water and are most commonly composed of shells and skeletal remains of marine plants and animals.

Glacial Marine Sediments

The majority of these sediments (mud, rocks, sand, and boulders) were deposited when the glaciers of the ice age melted and retreated toward the poles. These sediments are deposited today by icebergs, since in most cases, icebergs are pieces of glaciers that break off and float to sea and melt. These sediments are found primarily in high latitudes within the continental shelf.

Volcanic Sediments

These deposits, primarily pumice and ash, are the result of volcanic eruptions. They are found in both deep and shallow water in all the world's oceans.

UNIT 1—LESSON 4

OCEANOGRAPHIC ANALYSIS

OVERVIEW	OUTLINE
Evaluate wave-height data and recognize its uses and analysis procedures.	Wave-height analysis
Evaluate sea surface-temperature data and recognize its uses and analysis procedures.	Sea-surface temperature analysis
Evaluate layer-depth data and recognize its uses and analysis procedures.	Layer-depth analysis
Recognize how bathythermography is used and how vertical temperature gradients are computed.	Bathythermograph data

OCEANOGRAPHIC ANALYSIS

There are many different types of oceanographic analyses. Those listed in the outline above are but a few; however, they are the primary analyses used on a day-to-day basis throughout the fleet. The objective of the following lessons is to familiarize you with the need for such analyses, the evaluation of the data, and analysis procedures.

Learning Objective: Evaluate wave-height data and recognize its uses and analysis procedures.

WAVE-HEIGHT ANALYSIS

The state of the sea is ever important in naval operations. It may aid, hinder, or negate maneuvers and operations, and is a primary consideration in routing. Ocean transits are not conducted without taking climatic, current, and forecast sea conditions into consideration. For example, wintertime ocean crossings in the North Atlantic Ocean are primarily conducted along more southerly routes. These routes are longer, but climatically, they provide the best weather and seas. For current and future operations, knowing the location of favorable and unfavorable seas is one of your jobs and one of the reasons we analyze sea heights. In addition to transits, at-sea refuelings, replenishments, helo ops, and antisubmarine ops, are all impacted by the state of the sea.

There are different types of wave-height analyses. One may analyze wind waves, swell waves, combined waves, significant waves, etc. The only difference in the analyses is the wave type.

Heights, and directions of waves are plotted from shipboard synoptic observations. The plotted information consists of the following elements:

- a circle or dot designating the observation point
- a figure representing the wave period
- a figure representing the wave height

● an arrow representing the direction toward which the waves are moving.

Wave-height plots are shown in figure 1-4-1. Note that the wave period is not plotted or analyzed.

Analysis Procedures

As with any chart analysis, you should review past history, especially the most recent analysis. The most recent analysis is of primary importance, because waves are not very conservative. Sea heights are subject to significant change over relatively short periods of time. The most recent analysis gives you an idea of what to look for on the current chart. I recommend transferring the highest labeled sea-height contours (high sea areas) onto the current chart and beginning your analysis in one of these areas.

Another aid in analyzing sea heights is the current and past sea-level pressure (surface) charts. Because most waves are wind generated, the wind directions, speeds, fetch, and duration are elements that will help you with your analysis. These elements are either plotted on the surface chart or can be determined from the plotted data.

The sea-height analysis consists of contours drawn at 3-foot intervals, i.e., 3, 6, 9, 12. Much like isobaric analysis, you connect the reports of equal sea heights. Scan the chart for reports that provide a continuous closed contour. In the high sea areas, you might begin with a 9-foot contour.

Connecting points of equal sea heights seems easy; however, a proper analysis calls for far more than connecting a series of like sea-heights. For example, a single contour may outline hundreds or thousands of square miles based on the reported heights but be incorrect. The reason the contour could be wrong can often be attributed to the analyst not taking into account wind and wave directions. A proper analysis requires that you check the wind and wave directions, as well as the heights.

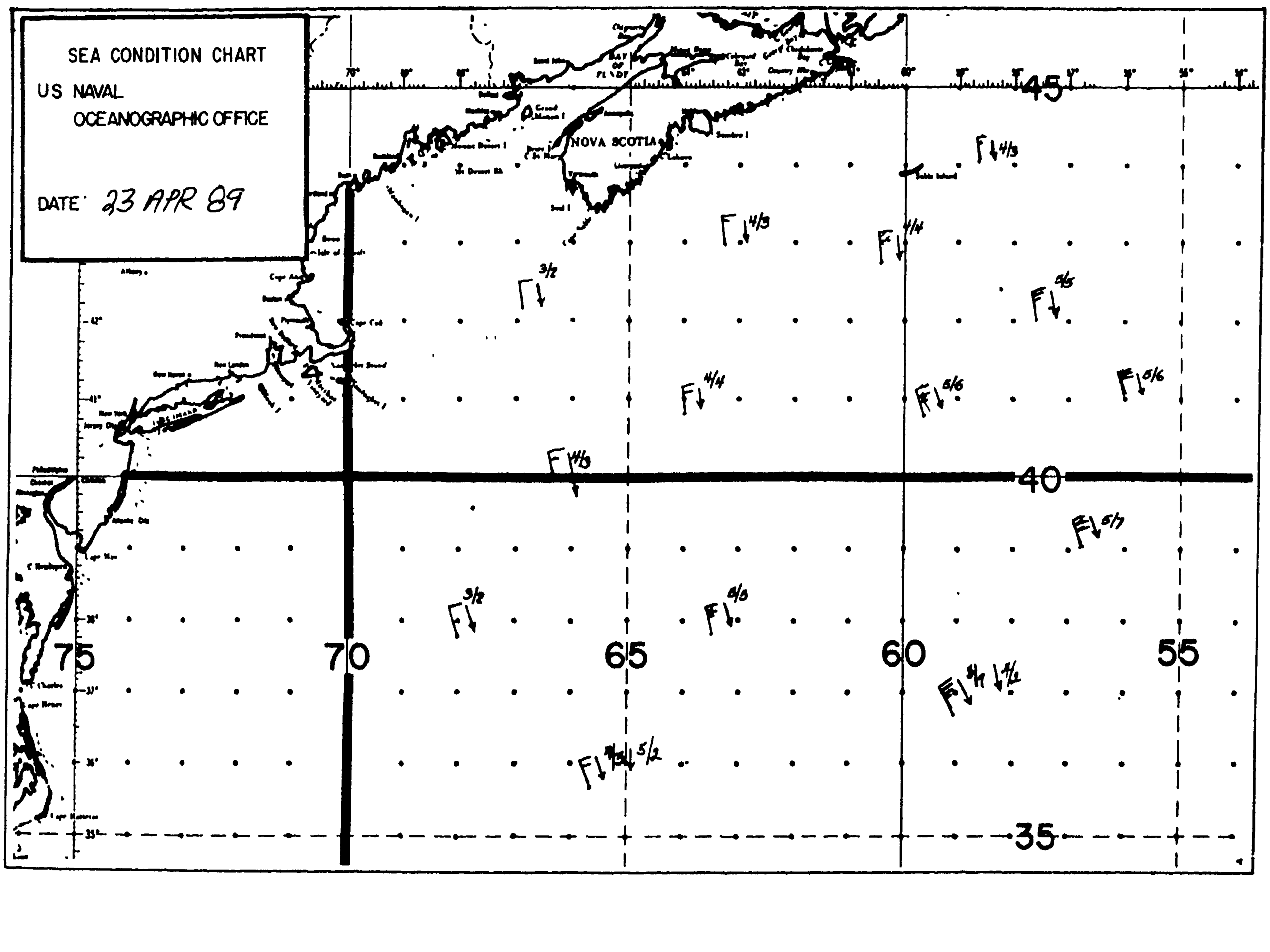

Figure 1-4-1.—Plotted sea condition chart.

Along coasts, the height of wind waves is controlled by the wind velocity (speed and direction), and bottom topography. If the wind is blowing onshore and is quite strong, the innermost sea-height contour might be quite high. With an offshore wind, the innermost contour will be small, usually 0 or 3. When the wind blows parallel to the shore, the sea heights may be large or small, depending on the speed and duration of the wind.

All sea heights near the shores of continents and large islands are influenced by land and sea breezes. Modification of the existing wind field by these breezes can increase or decrease sea heights. Also, strong gravity winds that form when cold dense continental air flows down from atop continental highlands produce high waves for short distances from shore.

Another factor affecting wave height is water depth. Shallow water, water that has a depth that is less than one-half the length of the waves passing over it, slows the waves and increases their height.

In the open sea, the height and direction of the sea is, for the most part, directly related to the wind. Where waves move with a current, the wavelengths increase and the heights lessen. The opposite holds true when seas oppose a current. In areas where strong currents oppose one another, waves can steepen even to the point of breaking. The North Wall of the Gulf Stream, where the Gulf Stream meets the Labrador Current, is one such area.

Sea-height contours are drawn in the form of closed loops or continuous lines that begin and end along a coast. The closed contours delineate maximum or minimum sea areas. See figure 1-4-2.

Practice Plotting Sea-height Charts

As is the case with any hand-drawn analysis, practice makes perfect. I recommend that you plot a number of sea-height charts. Analyze each one, and then have your chief or another experienced analyst check your work.

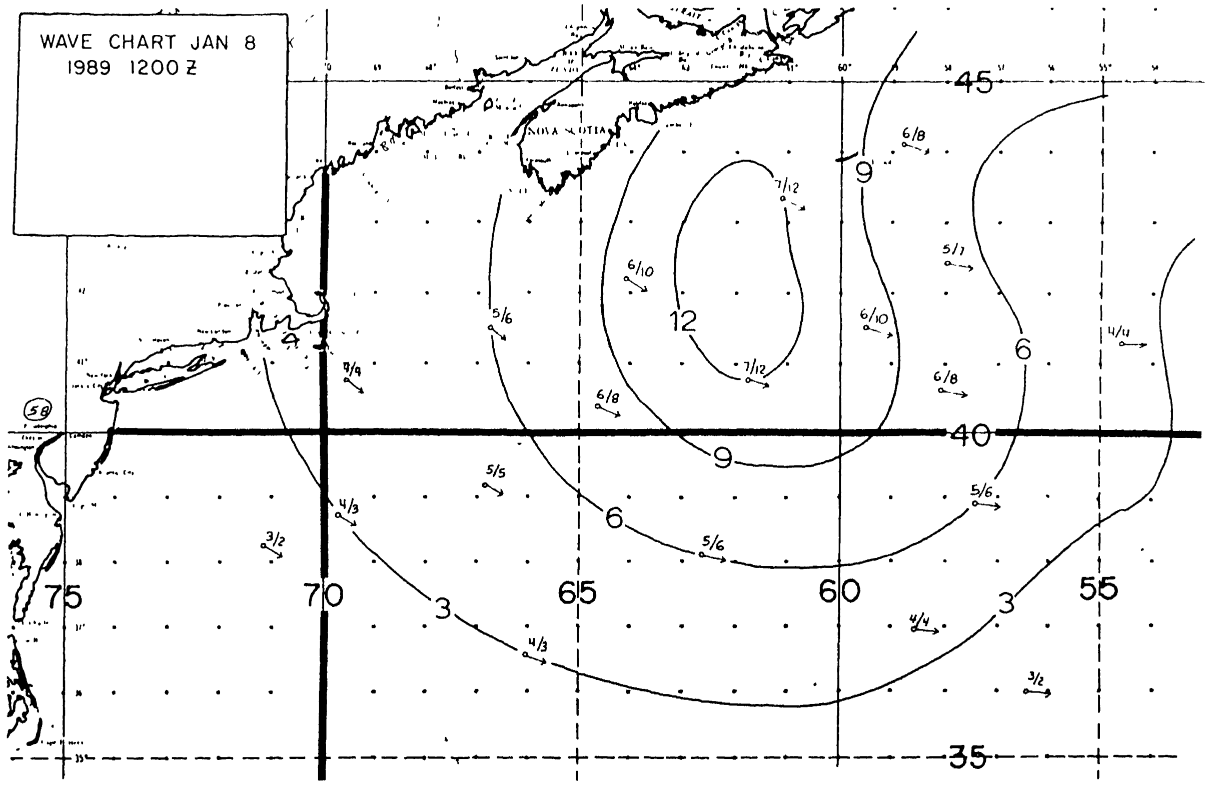

Figure 1-4-2.—Wave height analysis.

Learning Objective: Evaluate sea surface-temperature data and recognize its uses and analysis procedures.

SEA-SURFACE TEMPERATURE ANALYSIS

Sea-surface temperature (SST) observations are plotted and analyzed to delineate relative warm and cold surface water areas. The fundamental information derived from SST analysis has many uses. In search and rescue operations, the temperatures are used to determine survival times. Table 1-4-1 shows sea-water survival times based on temperature. In submarine and antisubmarine warfare operations, regions of strong SST gradients are extremely important because of their impact on sonar performance. And with regard to meteorology, sea-surface temperatures play an important role in the development and dissipation of sea fogs, thunderstorms, sea and land breezes, low clouds, and tropical storms.

Plotted Data

Usually, a single day's collection of SST observations is insufficient for the preparation of an SST regional analysis. Therefore, several days worth of SST observations are plotted on the same chart. The exact number of days may vary from command to command, but most charts consist of 5 days' worth of data. Such charts are referred to as composite charts, because they are composed of more than one day's data. Such an analysis is possible because seawater temperatures are quite conservative and are slow to change.

Erroneous SST values, and incorrect positioning of correct values can change the entire analysis picture as well as that of all the resultant products. Therefore, check all questionable temperatures.

Analysis Procedures

The analysis of sea-surface temperatures is quite subjective; however, if each analyst adheres to the same general rules, the hand-drawn product should be approximately the same for each individual analyst. The analysis is accomplished in much the same manner as meteorological charts. For example, the first step is to transpose past history onto the current chart. With SST charts, we use a yellow pencil to transpose one or two of the more prominent isotherms. The temperature patterns on the current chart will not differ a great deal from the history because the oceans are very conservative and the temperature patterns change very gradually. This tendency toward gradual change

Table 1-4-1.—Seawater Survival Times

Water Temp (°F)	Exhausted or Unconscious	Expected Survival Time
32.5	Less than 15 minutes	Less than 15 to 45 minutes
32.5 - 40.0	15-30 minutes	30-90 minutes
40.0 - 50.0	30-60 minutes	1 - 3 hours
50.0 - 60.0	1 - 2 hours	1 - 6 hours
60.0 - 70.0	2 - 7 hours	2 - 40 hours
70.0 - 80.0	3 - 12 hours	3 hours - indef
> 80.0	indefinite	indefinite

must always be kept in mind, and any data that reflects a major change in a temperature pattern should be closely examined.

With the history transposed, the next step is to draw the isotherms. Sea-surface isotherms are normally drawn at 2 °C intervals. However, in areas of weak horizontal temperature gradients it may be necessary to analyze the isotherms to the nearest 1 °C or even 1/2 °C.

Some of the things you should consider before starting your analysis are current structure, bottom topography, local characteristics, and prevailing winds.

CURRENT STRUCTURE.—Currents transport warm and cold water throughout the world's oceans. Knowing the current or currents that exist in an area will help you in evaluating the SST data and in drawing the isotherm patterns. For example, let's look at the Gulf Stream system of the western North Atlantic Ocean in the winter. Off the Virginia coast, typical Gulf water is warmer than 24 °C, while the inshore shelf and slope water have temperatures of 14 °C, and 18 °C, respectively. Seaward of the Gulf Stream, the SST of the Sargasso Sea is 24 °C. Also, north of Cape Hatteras the warm Gulf Stream meets the much colder Labrador current producing a tightly packed, wave-like isotherm pattern. The strong horizontal temperature gradient makes for a well-defined, sharp boundary on the cold-water side of the Gulf Stream, while the wave-like pattern is created by alternating extensions, or TONGUES, of cold and warm water. See figure 1-4-3.

On the warm-water side of the Gulf Stream there is little temperature contrast between the Gulf Stream and the water of the Sargasso Sea. Because of the large horizontal temperature gradient, this boundary is much more difficult to distinguish through SST analysis. Knowledge of such current information is invaluable in conducting your SST analysis.

BOTTOM TOPOGRAPHY.—The ocean floor becomes a factor in SST analysis in shallow waters. Isotherms and isobaths (lines of equal water depth) show marked similarity. The

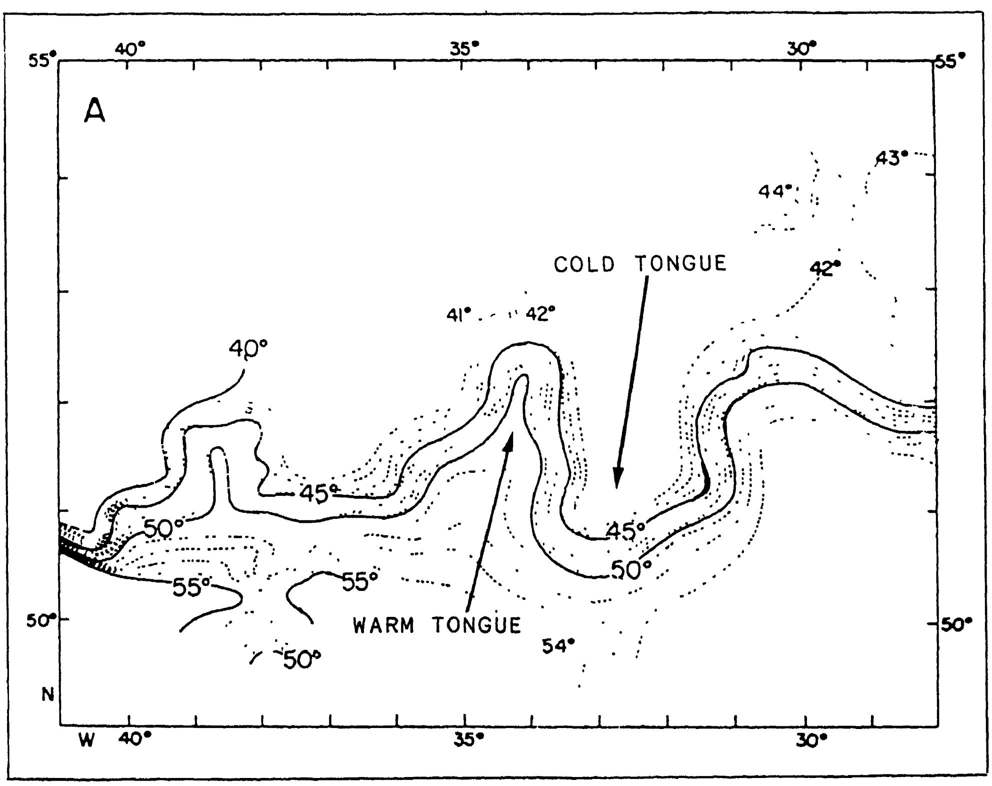

Figure 1-4-3.—Gulf Stream current structure of the western North Atlantic Ocean in the winter.

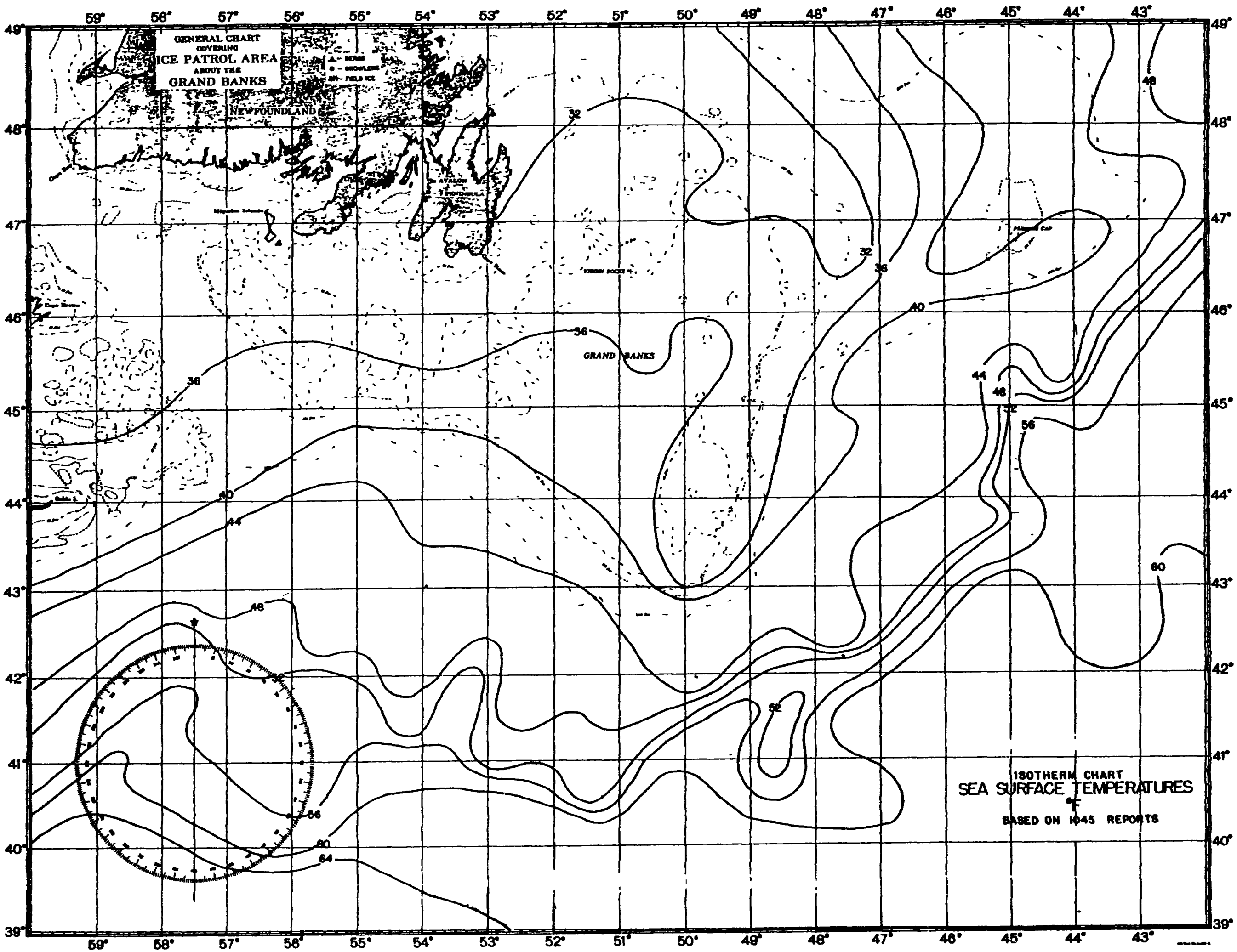

Figure 1-4-4.—Similarity of isobaths and isotherms (after USCG).

isotherms tend to follow the outline of the bottom contours. See figure 1-4-4.

LOCAL CHARACTERISTICS.—Some local characteristics of SST analysis are areas of freshwater runoff, areas of upwelling, and eddies.

Freshwater Runoff.—Some coastal regions of the world's oceans are affected by freshwater runoff from continents via major river systems. The intrusion of less saline, cold water can create cold tongues in these regions.

Upwelling.—Another area of distinct temperature patterns occurs in regions of upwelling. The sea-surface temperatures in these regions are colder than the water surrounding such regions. Also, depending on the strength of the upwelling, the sea-surface temperatures can be colder than what otherwise might be expected.

Eddies.—Eddies, independent circulations or rings of cold or warm water, are another feature of SST analysis. They form along major current boundaries and are most prevalent in the western portions of the oceans. For example, warm eddies form on the north side of the Gulf Stream and drift into the colder waters of the Labrador current. The warm eddies maintain a clockwise rotation. Cold eddies form on the south side of the Gulf Stream. They maintain a counterclockwise circulation. Eddies are difficult to delineate from plotted SST reports, because of their relatively small size (60 to 100 miles wide).

PREVAILING WINDS.—The changes that take place in SST patterns can primarily be attributed to the advection of cold or warm water brought about by the wind. Cross-current wind causes warm or cold water advection, while wind that blows parallel to ocean currents causes no advective change in the SST.

Learning Objective: Evaluate layer-depth data and recognize its uses and analysis procedures.

LAYER-DEPTH ANALYSIS

The concept of the three-layered ocean—mixed layer, main thermocline, and deep layer—was mentioned earlier in this unit. Of these three layers, the mixed layer is the most variable in its properties (primarily depth), and requires considerable attention.

Another layer of high variability and of great importance in antisubmarine warfare is the sonic layer. The sonic layer is a layer that basically traps sound waves. The sonic-layer depth is the level of maximum sound velocity based primarily on temperature, but also controlled by density and pressure. The sonic-layer depth and mixed-layer depth often coincide.

Mixed Layer

We determine layer depths from temperature versus depth profiles obtained in bathythermograph observations. The mixed-layer depth is determined by finding the first subsurface depth with a temperature at least 1 °C colder than the surface temperature. From this point, proceed back up the profile to the previous depth—this is the mixed-layer depth, or MLD. Refer to the example in figure 1-4-5.

The temperature-versus-depth profile in this example shows an isothermal layer of 24.5 °C water in the first 15 meters. Between 15 meters and 55 meters the temperature decreases to 22.1 °C. This temperature is maintained to a depth of 75 meters. Between 75 meters and the last

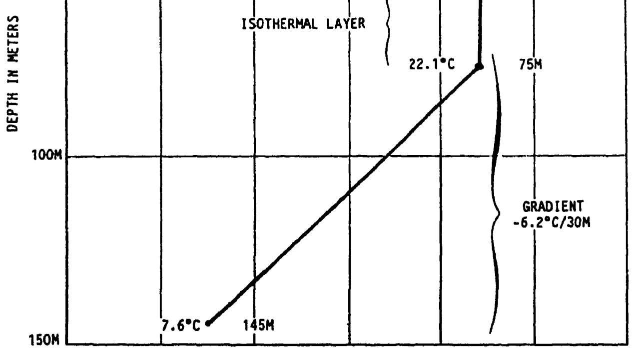

Figure 1-4-5.—Mixed-layer depth (MLD) determined using BT analysis.

reported depth of 145 meters the temperature drops rapidly to 7.6 °C.

The first reported depth with a temperature at least 1 °C colder than the surface temperature is 55 meters. The preceding temperature is 24.5 °C at 15 meters. This is the depth of the mixed layer. Had the isothermal layer at the surface not been in existence and the temperature had simply decreased from the surface to 55 meters, the MLD would have been at the surface. In other words, there would have been no mixed layer.

The importance of the mixed layer lies in the fact that it is most often synonymous with the sonic layer and plays a vital role in ASW operations. The mixed layer also plays a key role in the food chain. Some of the most productive fishing areas are found where strong mechanical and/or convective mixing occur.

Sonic Layer

The sonic layer depth (SLD) can also be determined from temperature-versus-depth profiles. The depth where the warmest temperature occurs is normally the SLD, but not always.

The speed of sound in water is normally greatest near the surface, where the temperature is warmest, and decreases with depth as the temperature decreases. However, at greater depths, sound speed increases because pressure becomes the dominant controlling factor.

Figure 1-4-6 is a BT profile that shows the MLD and SLD at different depths. The SST is 24.5 °C, and the temperature increases to 26.0 °C at 10 meters. The temperature then decreases gradually to 25.1 °C at 28 meters before falling rapidly to 15.6 °C at 80 meters. The MLD in this example is at 28 meters, while the SLD is at 10 meters. The SLD is at 10 meters because this is the level with the highest temperature.

Plotted Data

Like SST data, more than 1 day's worth of layer-depth data is plotted on the same chart. See figure 1-4-7. Plotted layer depths may or may not have a (+) or a (*p*) plotted behind the report.

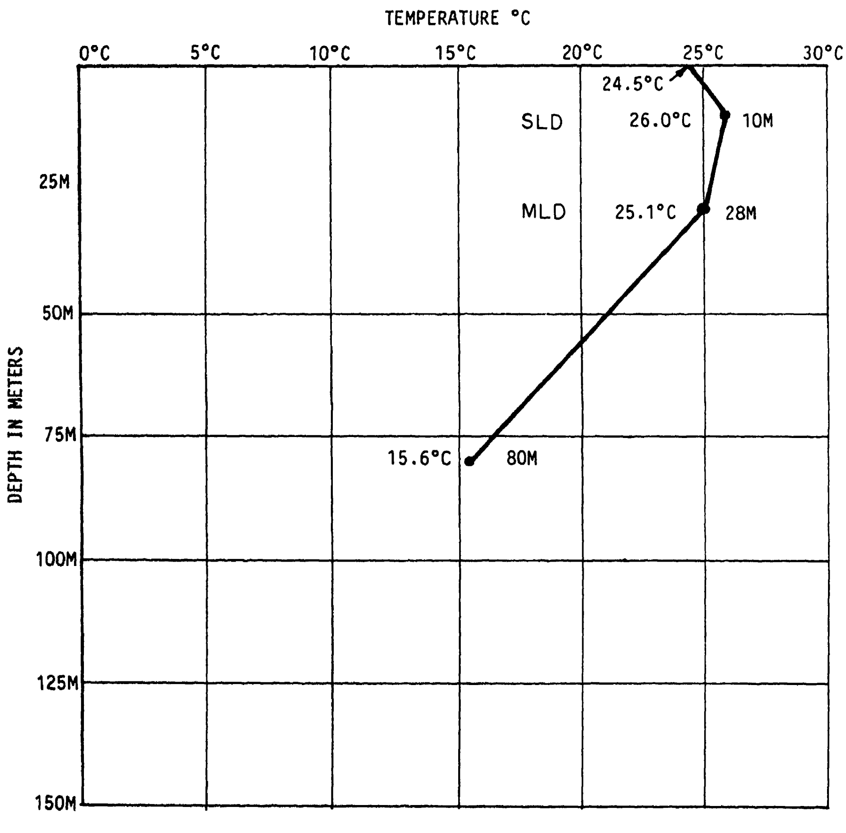

Figure 1-4-6.—Sonic-layer depth (SLD) determined using BT analysis.

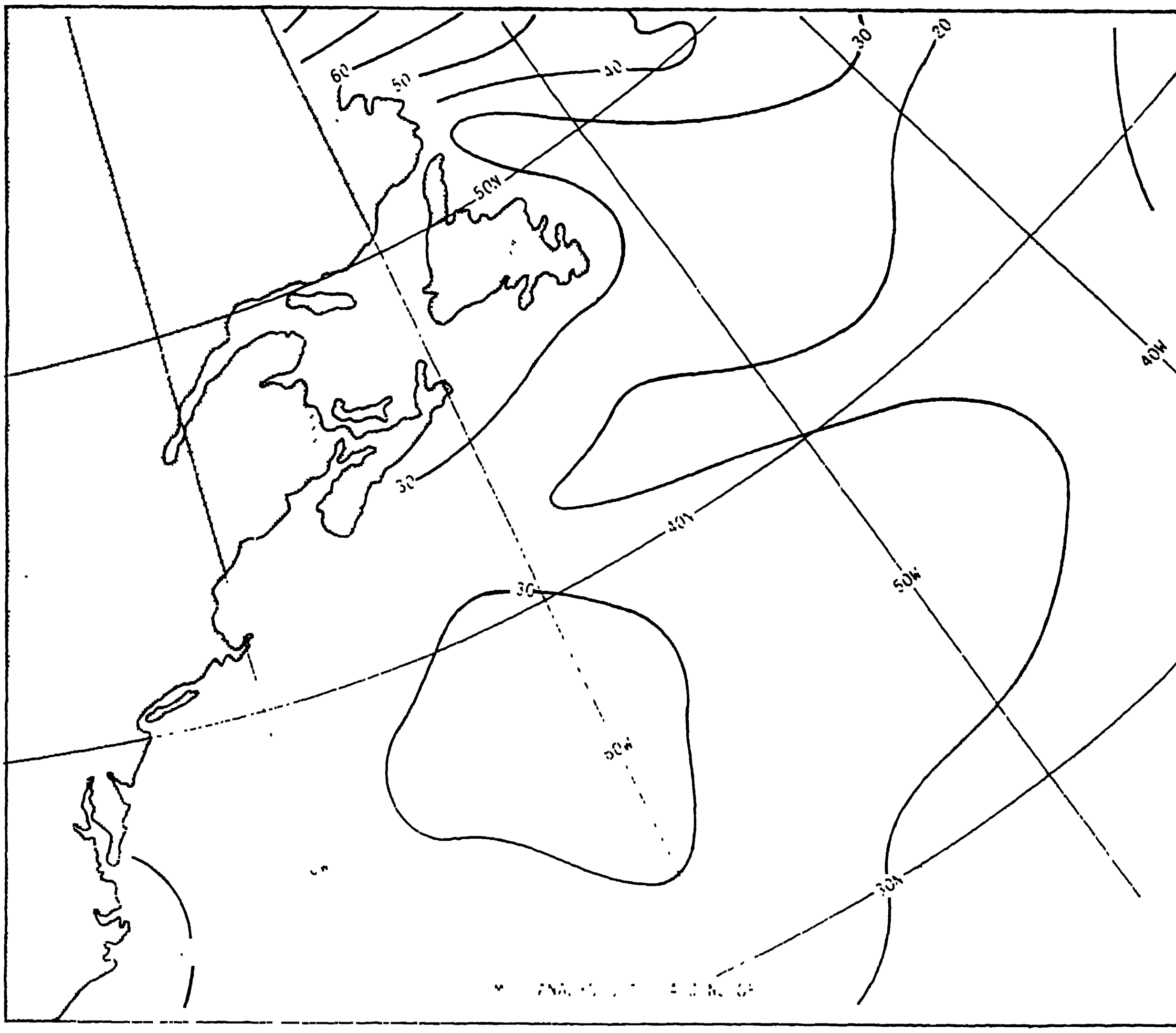

Figure 1-4-7.—Example of a MLD chart.

A (+) denotes the reported value is or may be greater than that indicated. A (*p*) is plotted if a positive temperature gradient exists from the surface to the MLD. If both a positive gradient and a possibly deeper layer depth exists, the (*p*) and (+) are both plotted.

Analysis Procedure

The mixed layer is analyzed by drawing isopleths of equal layer depth. Like isobars, these lines should be smooth flowing and never cross or touch. Unlike isobars, there will be no sharp turns or kinks. Isopleths are drawn at 60-meter intervals in winter and 15-meter intervals in summer. In winter, the mixed layer extends to much greater depths than in summer; therefore, the 60-foot interval is used. In summer, the mixed layer is much shallower and the 15-meter interval is required.

As you might expect, there are even less bathythermograph observations to work with than there are SST observations. Therefore, past history is extremely important. I recommend that you place the last analysis under the current plotted chart and do the current analysis on a light table. If a light table is not available, use a yellow pencil and transpose as many of the historical isopleths as necessary onto the current chart.

Another aid in regions with few or no layer-depth observations is the latest SST analysis. The SST analysis is used to determine the SST advection pattern, which in turn is used to evaluate reported layer depths and to justify increasing or decreasing layer depths in a region.

In regions where cold SST advection takes place, the mixed layer generally increases; it gets deeper. The opposite applies in regions of warm advection; the layer depth generally decreases.

Variation in the depth of the sonic layer may occur as a result of several different factors, one of which is diurnal heating and cooling. Usually, the near-surface diurnal temperature variation averages about 0.5 °C; however, under extreme conditions the SST may vary as much as 3 °C. As the sea surface heats during the day, a conditional thermocline (NOT to be confused with the main thermocline) often develops within 10 meters of the surface. The maximum temperature gradient associated with this conditional thermocline occurs during the late afternoon, and the normal layer depth is all but destroyed. Such an occurrence is referred to as the "afternoon effect." At night when the sea surface cools, the conditional thermocline disappears and the sonic layer once again decends to the depth of the main thermocline. The fact that we plot daytime as well as nighttime sea-surface temperatures on composite charts helps to overcome such errors in layer-depth (LD) analysis.

Learning Objective: Recognize how bathythermograph data is used and how vertical temperature gradients are computed.

BATHYTHERMOGRAPH DATA

As was already stated, the temperature data provided in BT observations is used in SST and LD analysis. At sea, the on-scene BT data is also used to evaluate the sonar ranges and environmental lines supplied in Fleet Numerical Oceanography Center's ASW products, such as Ship Helicopter Acoustic Range Prediction System (SHARPS) and Acoustic Sensor Range Prediction System (ASRAPS).

Antisubmarine forces use the data to determine the on-scene layer depth, sonar ranges, and to evaluate sonar performance.

The depth of the sonic layer, water temperature, and the vertical temperature gradients in and beneath the layer are the factors used to determine what happens to transmitted sonar pulses. We have already discussed the SLD and the effect of temperature on sound speed. The last factor, the vertical temperature gradients, controls the sound ray paths.

Vertical Temperature Gradients

Vertical temperature gradients are computed from the temperatures and depths reported in BT observations. The vertical temperature gradients show the change in temperature over a given vertical distance. The gradients may be positive or negative. Positive gradients show an increase in temperature with depth, while negative gradients show a decrease in temperature with depth. The greater the change in temperature (+) or (−), the stronger the gradient.

Positive gradients refract sound waves upward toward the sea surface. Negative gradients refract sound waves down toward the ocean bottom. Various combinations of positive and negative gradients exist within the mixed and/or sonic layer, while the main and conditional thermoclines have strong negative temperature gradients.

Vertical temperature gradients are computed to assess their effect on sound waves. For example, go back to the temperature-versus-depth profile provided in figure 1-4-5. The temperature difference between the surface and 15 meters is zero. Because there is no change in temperature within the 15 meters, the gradient is 0.0 °C, and the sound wave would be refracted upward slightly. Between 15 meters and 55 meters, the temperature decreases 2.4 °C per 40 meters, the 40 meters being the difference between the 15 and 55 meter depths. For standardization purposes, all gradients are computed per 31 meters. Therefore, the gradient of −2.4 °C per 40 meters must be changed to reflect the change in temperature per 31 meters. This is done using a ratio formula. In this case, −2.4 °C is to 40 meters as X (the unknown) is to 31.

$$-2.4/40 = X/31$$

$$40X = -74.4$$

$$X = -1.9\,^{\circ}\mathrm{C} \text{ per 31 meters}$$

Because the temperature is decreasing with depth, the gradient is classified as a negative (−1.9 °C per 31 meters). Sound waves in this layer would be refracted down toward the bottom. For training purposes, plot a few BT observations on graph paper, and determine the MLD, SLD, and vertical temperature gradients. Have your chief or immediate supervisor check your work.

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UNIT 2

FUNDAMENTALS OF HYDROACOUSTICS

FOREWORD

The term *hydroacoustics* can be broken down into two words: *hydro*, meaning water, and *acoustics*, meaning sound. Hydroacoustics is the study of sound in water. In the case of the Navy, it is the study of sound energy in seawater.

The Navy's greatest interest in hydroacoustics is related to submarine and antisubmarine warfare or more precisely the effect of seawater on sonar. Certain properties of seawater control sound as it propagates through the water. Their effect may aid or hinder sonar operations.

In this unit, we will discuss the seawater properties that control sound in Lesson 1, and sound propagation paths in Lesson 2.

UNIT 2—LESSON 1

PROPERTIES OF SOUND

OVERVIEW	OUTLINE
Recognize the three basic elements necessary for the production of sound and which one controls the speed of sound.	Sound production
Identify the various properties of sound waves.	Sound waves
Define energy loss or spreading loss as it pertains to sound waves.	Energy loss
Define Doppler effect, and recognize how it effects the pitch and frequency of sound.	Doppler

PROPERTIES OF SOUND

Sound as related to oceanography has taken on significant meaning to Aerographer's Mates; consequently, it is necessary that you become familiar with some of the fundamental concepts concerning the properties of sound.

Learning Objective: Recognize the three basic elements necessary for the production of sound and which one controls the speed of sound.

SOUND PRODUCTION

Sound is the physical cause of hearing. Anything that you hear is a sound. However, before sound can be produced, three basic elements must be present: **SOUND SOURCE**, a **MEDIUM**, and a **DETECTOR**. See figure 2-1-1.

Source

Any object that vibrates or disturbs the medium around it may become a sound source.

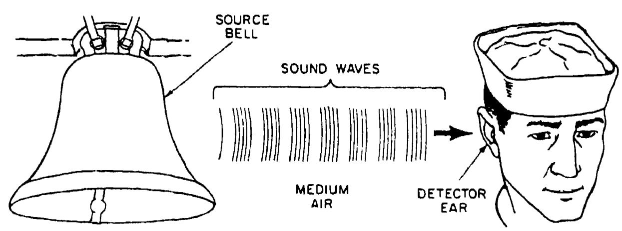

Figure 2-1-1.—The three elements of sound.

Bells, radio speaker diaphragms, and stringed instruments are familiar sound sources. The sound source is the initial requirement in the production of sound.

Medium

The second element needed to produce sound, the medium, is the element that carries the sound. Your alarm clock goes off and you are awakened by the sound. The sound reaches your ears through the air in your bedroom. Air is a medium. Particles in the air carry the sound to you. Noises or sound are also heard underwater, because particles in water carry sound. A more dense

medium than that of air or water is that of steel. A person can detect an approaching train far faster by pressing his or her ear to a train rail than by standing alongside the track listening for its approach.

The medium is the controller of sound. It controls how far and how fast sound travels. Sound travels faster, farther, and with more ease through mediums of high elasticity and density. In general, solids are better transmitters of sound than either liquids or gases.

SPEED OF SOUND—The speed of sound in air is approximately 331.5 m/sec at 0 °C. Sound speed lowers at lower temperatures and increases at higher temperatures. Sound speed increases at a rate of approximately 0.6 m/sec for every 1 °C increase in temperature.

The speed of sound in water is about 4 times greater than the speed of sound in air. Seawater is more dense than fresh water; therefore, at the same temperature, the speed of sound in sea will be slightly greater than the speed of sound in fresh water.

In steel, sound speed is about 15 times greater than in air. Sound travels at approximately 5,200 m/sec through a thin steel rod.

Detector

A detector acts as a receiver of sound. The detector permits us to tell whether sound has been produced. Sound travels in waves that move radially (360 degrees) from their source, and only a small part of a wave's energy reaches a detector. Therefore, detectors often contain amplifiers to boost a signal's energy, thereby permitting reception of weak signals.

Learning Objective: Identify the various properties of sound waves.

SOUND WAVES

Sound travels in the form of waves. Sound waves are brought about by vibrations within a medium. The vibrations produce compressions (pressure increases) and rarefactions (pressure decreases) that impact the particles within the medium. The particles do not physically move, but the energy is transferred from particle to particle. This is how the sound travels. A single sound wave consists of one compression and one rarefaction.

Wavelength

The length of a sound wave is the distance between any two successive compressions or rarefractions. Figure 2-1-2 illustrates a longitudinal wave with its compressions and rarefractions. One complete wavelength is called a cycle. Wavelengths vary depending on the number of cycles per second produced by the sound source.

Frequency

The number of cycles per second (cps) is a measure of a sound's frequency. The higher the frequency, the shorter the wavelengths, and vice versa.

Frequencies are measured in the Hertz system, 1 hertz (Hz) is equal to 1 cycle per second (cps). Frequencies of 1000 Hz or more are measured in kilohertz (kHz). The average human hears sounds between 20 Hz and 15 kHz, while sounds below

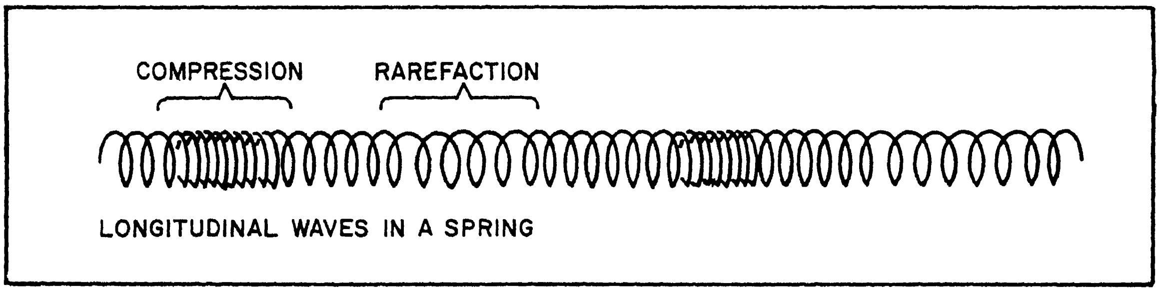

Figure 2-1-2.—Longitudinal wave.

20 Hz and above 15 kHz are normally beyond the human range of hearing.

Pitch

The pitch of a sound depends on the frequency of the sound as received at a detector. The human ear detects sounds and classifies them based on the sound quality. Some sounds are harsh, while others are pleasant. Pitch is a subjective quality dependent on the receiver.

Intensity and Loudness

Intensity and loudness are often mistaken as having the same meaning. Although related, they are not the same. Intensity is a measure of a sound's energy, while loudness is the effect on the detector. If sound intensity is increased, the loudness is increased but not in direct proportion. To double the loudness of sound requires about a tenfold increase in the sound's intensity.

Sound intensity is measured in decibels (dB). A decibel is the unit used to express relative power (intensity) differences between acoustic signals (sounds). Decibel levels are assigned based on a sound's intensity compared to an established standard. Some common intensity levels are as follows: a whisper, 10 to 20 dB; heavy street traffic, 70 to 80 dB; thunder, 110 dB.

Learning Objective: Define energy loss or spreading loss as it pertains to sound waves.

ENERGY LOSS

As a sound wave moves away from its source, it spreads out. The energy within the wave decreases as the wave spreads through an increasingly large area. Thus, the wave energy per unit area decreases as the distance from the sound source increases. This loss of energy due to distance is known as spreading loss.

Learning Objective: Define Doppler effect, and recognize how it effects the pitch and frequency of sound.

DOPPLER

The Doppler effect is the apparent change in a sound due to motion. It is a change in pitch (a detector variable) without a frequency change occurring (a sound source variable). The change in pitch is brought about by the relative motion of a sound source and a detector. For example, we hear the whistle of an approaching train. The frequency of the whistle does not change as the train approaches, but our ears detect an increase in the pitch. The increase in pitch is caused by the compression of sound waves. The train acts to "push" the sound waves toward us. The sound waves arrive at a faster rate than they would if the train was not moving. Then, as the train goes by, the sound waves arrive at a much slower rate. The train is now pushing the sound waves away from us. The sound waves to the rear of the train spread farther apart as the train moves farther away from our position, and the effect is one of lower pitch.

UNIT 2—LESSON 2

SOUND PROPAGATION IN SEAWATER

OVERVIEW	OUTLINE
Define sound velocity, and describe the effect of temperature, pressure, and salinity on sound.	Sound velocity
Explain why sound propagates along more or less curved paths, and describe the five basic sound ray patterns and their attendant temperature and sound velocity profiles.	
Differentiate between active and passive sonar, define the two modes of active sonar search, and describe the propagation paths used with each mode.	Active and passive sonar
Define and differentiate between the elements used in the active and passive sonar equations.	

SOUND PROPAGATION IN SEAWATER

In physics, the word *propagate* means to cause (e.g., a wave) to move through a medium. In our study of sound, we learned that the medium controls sound. In this lesson, we will look at the effect of the sea on sound waves as they move through it.

Learning Objective: Define sound velocity, and describe the effect of temperature, pressure, and salinity on sound.

SOUND VELOCITY

Sound velocity takes into account the speed and direction of sound rays. The direction or path that sound energy takes as it moves through the water is primarily a function of sound speed.

Sound Speed

The speed of sound in the sea is a function of water temperature, pressure, and salinity. Of these three variables, temperature is the most important. It is the primary controller of sound speed, and therefore direction, in the upper 300 meters (1,000 feet) of seawater. In general, sound speed increases 2.4 m/sec for every 1 °C increase in temperature.

The effect of pressure on sound speed is a function of depth. The greater the depth, the greater the pressure; the greater the pressure, the greater the sound speed. Sound speed increases approximately 1.7 m/sec per 100 meters of depth. Pressure is the dominant sound speed controller below 300 meters, because below 300 meters, the temperature is relatively constant.

The effect of salinity on sound speed is slight in the open sea, because salinity values are pretty much constant. The affect of salinity on sound speed is greatest where there is a significant influx of fresh water or where surface evaporation creates high salinity. A one part per thousand (1 ‰) increase in salinity increases sound speed 1.4 m/sec.

SOUND-VELOCITY PROFILE (SVP).— A sound-velocity profile is simply a graphic representation of speed versus depth. See figure 2-2-1. Sound-velocity profiles are constructed from sound-speed nomograms based on temperature, depth, and salinity. They can also be constructed from bathythermograph soundings by computing the sound speed at significant and mandatory depths. An SVP provides surface sound speed, depth of maximum sound speed (sonic-layer depth), and layers where sound travels great distances (ducts and sound channels).

Sonic-Layer Depth (SLD).—The sonic-layer depth is the depth of maximum sound speed. In most instances, the SLD is the same as the

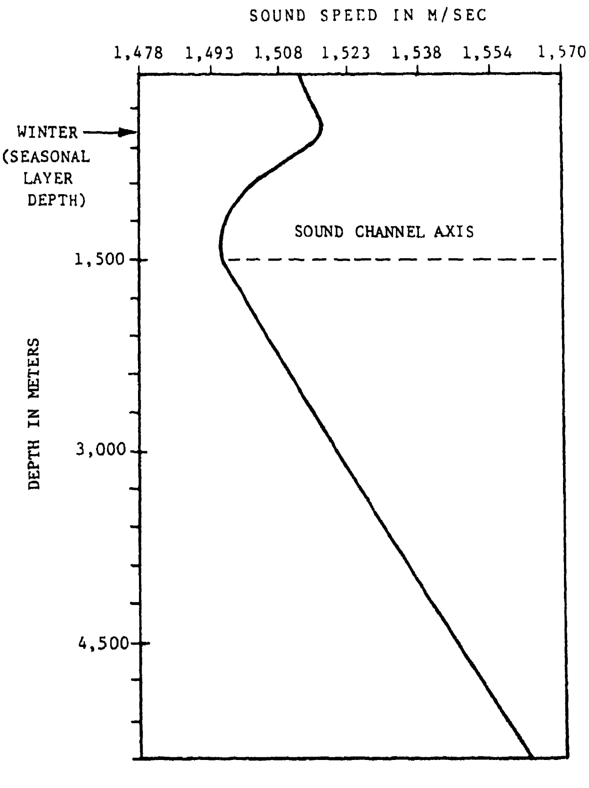

Figure 2-2-1.—Basic sound-speed structure of the deep ocean.

mixed-layer depth (MLD). The SLD can be determined from a BT trace. A negative-temperature gradient (temperature decreasing with depth), within certain limits, compensates for an increase in sound speed with depth due to pressure; this results in a constant sound speed with depth. These gradient limits per 30 meters of depth are as follows:

- 0.1 °C per 30 meters in water 4.4 °C
- 0.17 °C per 30 meters in water 12.8 °C
- 0.22 °C per 30 meters in water 18.3 °C.

Temperature gradients that are more negative than those listed (temperature decreases at a greater rate) result in decreasing sound speed with depth. Gradients that are more positive result in increasing sound speed with depth. Of course, sound speed increases with depth when the water temperature is constant because of the increasing pressure.

The SLD can be determined from a BT trace by considering the following criteria:

1. If the maximum temperature is at the surface, and the gradient is more negative than the limits listed, the SLD is zero. It's at the surface.
2. If the BT trace is isothermal or has a slight negative gradient (less than the stated limits) and then becomes more negative, the SLD is at the bottom of the isothermal or slightly negative gradient layer.
3. If the maximum temperature occurs at a depth other than the surface, this is the SLD, unless the gradient below depth of the maximum temperature is less than the stated limits.

When predicting sonar ranges, in-layer and below-layer ranges are computed. The term *in-layer* pertains to the layer of water above the SLD,

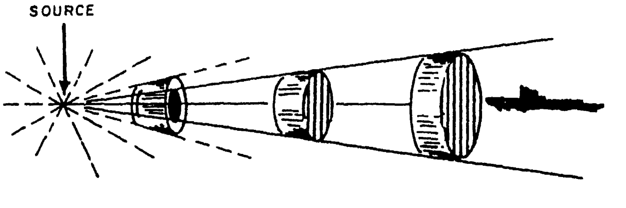

Figure 2-2-2.—Outgoing ping showing shape of beam pattern and divergence of sound rays.

while below-layer pertains to the layer beneath the SLD.

Learning Objective: Explain why sound propagates along more or less curved paths, and describe the five basic sound ray patterns and their attendant temperature and sound velocity profiles.

Sound Paths

As sound energy leaves a sound source it travels in waves. The sound waves expand as they move away from the source. See figure 2-2-2. A sound wave's path of travel is dependent on its speed and any matter in its path. Sound, like light, is refracted, reflected, and scattered.

REFRACTION.—As a sound wave moves through the sea, it travels along a curved path. The path is curved, because sound speed varies along the wave front. Sound waves bend (are refracted) in the direction of the slower sound speeds. This is the fundamental principle of sonar-range prediction and is derived from Snell's law. Snell's law states that a sound ray propagating through a region with one sound speed will change direction (be refracted) on entering a region having a different sound speed.

The degree of refraction is proportional to the sound-speed gradient. The greater the change in speed over a given distance or depth, the greater the refraction. The gradient is a function of speed versus depth or distance. For example, in a layer of water where sound speed decreases rapidly with depth (a strong negative-velocity gradient), sound waves bend sharply downward. Sound rays refract upward if sound speed increases with depth (a positive-velocity gradient). Figure 2-2-3 illustrates the five basic sound-transmission patterns. The BT sounding and SVP which bring about these paths accompany each pattern.

Straight Rays.—Sound rays travel in straight lines only where the speed is everywhere constant (isovelocity); no change in velocity with depth. Straight sound rays occur when the temperature profile is slightly negative (a decrease of about 1 °C per 30 meters of depth). Long sonar ranges are possible when this type of profile exists.

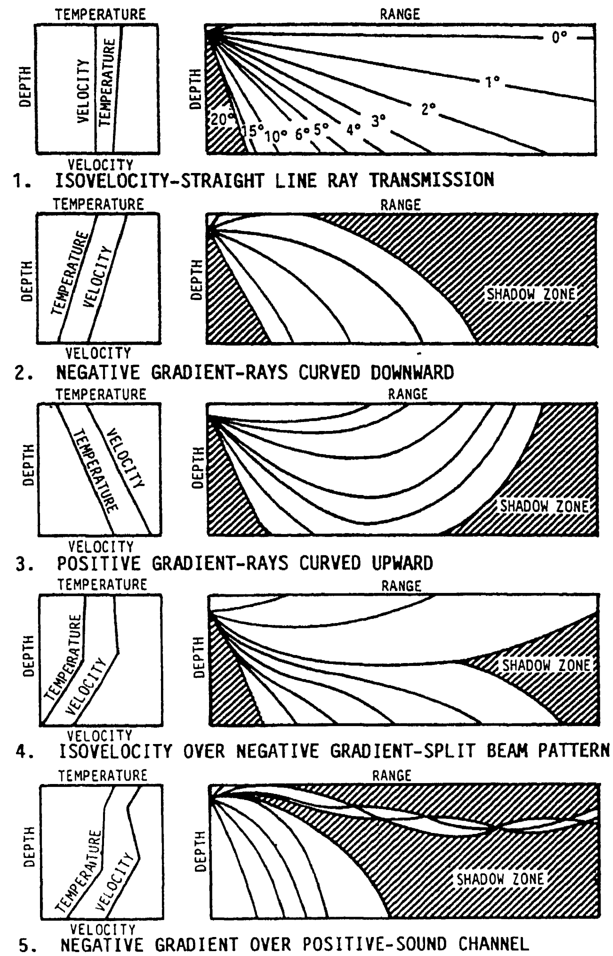

Figure 2-2-3.—Representative sound patterns based on temperature and sound-velocity gradients.

Rays Curved Downward.—A negative-temperature gradient (temperature decreasing with depth) produces a negative-velocity gradient. The sound rays leave the sonar and are bent downward, thereby limiting sonars to very short ranges. For example, a decrease in temperature of .56 °C in the first 10 meters causes the sound beam to miss a shallow target at a range of 1 km. This is a common occurrence in the near-surface layer. Beyond the range of the downward bending sound rays, sound intensity is negligible. This area is known as a shadow zone.

Rays Curved Upward.—A positive-temperature gradient causes sound speed to increase with increasing depth, and sound rays to refract upward. Longer ranges are attained with this type gradient, especially if the sea is relatively smooth. As the rays bend upward and

strike the sea surface, they are repeatedly reflected to longer ranges.

Split-beam Pattern.—A split-beam pattern occurs when the temperature gradient in the near-surface layer is isothermal, and negative below. Sound rays from a sonar split at the depth of the gradient change. Part of the sound rays are refracted upward toward the surface, and part are refracted downward toward the bottom. At the point where the rays split, a shadow zone exists. A submarine operating at the split depth improves its chances of avoiding detection.

Sound Channel.—A sound channel occurs when a negative-velocity gradient overlies an isovelocity or positive-velocity gradient. The depth where the velocity gradient changes from negative to positive is the axis of the sound channel. The axis is the level of minimum sound speed. The sound rays on both sides of the axis travel faster than the rays in the center. And since sound refracts toward slower sound speeds, the faster rays are continually refracted toward the axis.

REFLECTION.—Sound waves that strike solid surfaces have all or a portion of their energy redirected or absorbed. The surface or object struck determines if the sound energy is reflected, scattered, or absorbed.

Reflected sound energy can be good or bad. The type or quality of reflected sound is dependent on the surface from which the sound bounces. For example, a smooth hard surface is a good reflector. Sound waves bounce off such surfaces specularly (like a mirror) and lose little of their energy. On the other hand, an irregular hard surface is not a good reflector. The sound waves are reflected in many different directions and lose a good deal of their energy. This type of reflective energy loss is known as scattering.

Sound energy in the sea is scattered by the sea surface, sea floor, and suspended matter. Because the sea surface is rarely smooth, it is more apt to scatter sound than to reflect it specularly. A rough or rocky bottom also disperses or scatters sound energy.

In contrast to these rough surfaces, a smooth rock ocean bottom is perhaps the best reflector of sound in the sea. A smooth sand bottom also reflects sound very effectively. The sea surface, if it is calm, is also a good reflector.

REVERBERATION.—Reverberation is noise or interference at a sonar receiver, which makes target detection very difficult. This interference is caused by scattered sound energy being reflected back to the sonar receiver. There are three types of reverberation: surface, volume, and bottom.

Surface Reverberation.—Surface reverberation is a product of surface wave action. At short ranges, surface scattering increases with wind speeds between 7 and 18 knots. Above 18 knots, a further increase in the surface-reverberation level is prevented by a sound screen of entrapped air bubbles. The air bubbles form near the surface and are caused by the wave action.

Volume Reverberation.—Volume reverberation is caused by scatterers or reflectors in the water such as fish, marine organisms, suspended solids, and bubbles. Volume scatterers are not uniformly distributed in depth, but tend to be concentrated in a diffuse layer known as the deep-scattering layer.

The deep-scattering layer is found in tropical waters at depths between 100 and 400 fathoms. The intensity of the scattering is a function of sonar frequency (some sonar frequencies are affected to a greater degree than others) and the density of the organisms in the layer. In the Northern Hemisphere, the maximum volume reverberation occurs in March and the minimum in November.

Bottom Reverberation.—Bottom composition and roughness govern the degree of reverberation that contributes to the masking of target echoes. In theory, the amount of bottom reverberation is directly related to the roughness and composition of the sea floor. However, the problem of bottom reverberation is a bit more complicated. Scientists consider the ocean floor to be a two-dimensional volumetric scattering surface. In other words, sound is not only reflected off the sea floor but also from formations of rock beneath the sea floor.

Also, bottom roughness can be slight or great, and the wavelength component of the reflected sound can range from microns to miles. The following conclusions were drawn from a Russian study (Jitkovskey and Volovova, 1965): (1) When bottom roughness is large compared to the wavelength of the sound being bounced off it, the amount of sound energy scattered back to the receiver (back scattering) is independent of frequency and (2) when the bottom roughness is small compared to the wavelength of the

transmitted sound, scattering strength expands with increasing frequency.

Another problem created at the ocean bottom is one of absorption. When the bottom is composed of soft mud, sound energy is absorbed. Absorption also occurs as sound propagates through the sea, and the energy is converted to heat.

ATTENUATION.—Attenuation is the energy loss that occurs in propagated sound waves due to scattering and absorption.

Learning Objective: Differentiate between active and passive sonar; define the modes of active-sonar search; and describe the propagation paths used with each mode.

ACTIVE AND PASSIVE SONAR

Sonar (SOund NAvigation and Ranging) was originally designed to assist surface ships to navigate in bad weather. Later, it was employed on submarines, and today it is our primary means of locating submarines. There are two types of sonar searches: active and passive. An active sonar employs a transmitter to send out sound pulses and a receiver to record returning echoes. A passive sonar listens for sounds generated by other ships and submarines.

Active Sonar

Active-sonar search is classified into two modes: shallow-water transmissions and deep-water transmissions. Theoretically, the essential difference between shallow- and deep-water transmissions is the interference effects produced by the multiple reflections of sound in shallow water.

Shallow water is classified as water less than 100 fathoms—that is, water over a continental shelf. Deep water is classified as water 1,000 fathoms or deeper. Water between 100 and 1,000 fathoms deep is most common over continental slopes. It is not considered overly important in active sonar operations because it exists in such a small portion of the world's oceans.

SHALLOW-WATER TRANSMISSIONS.—Shallow-water propagation paths are classified as direct path and surface duct.

Direct Path.—Direct path is the simplest mode. Direct path sound propagation occurs where there is an approximate straight-line path between the sound source and the receiver, with no reflection from any other source and only one change of direction due to refraction.

Surface Duct.—A surface duct is simply a near-surface layer that traps sound energy. Surface ducts exist in the ocean if the following conditions are met:

1. The temperature increases with depth.
2. An isothermal layer is near the surface.

In condition 1, sound velocity increases as the temperature increases. In condition 2, there is no temperature or salinity gradient; however, the increase in pressure with depth causes the sound velocity to increase with depth.

The greater the depth of a duct, the greater the difference between the surface velocity and the velocity at depth. There are also a greater number of sound rays trapped in the duct. Of course, the efficiency of a surface duct in transporting sound is dependent also upon the smoothness of the sea surface.

ENVIRONMENTAL CONTROLS.—The success of active sonar searches in shallow water depends a great deal on environmental factors. Temperature gradients, horizontal as well as vertical; water depth; and the physical characteristics of the sea surface and bottom all impact shallow-water transmissions. Of these controls, water depth is the most important.

Water depth determines the range and angle at which sound rays strike the bottom (angle of incidence) and to some extent the types of transmission paths that occur.

Variations in the vertical temperature gradient, which result in sound speed variations, are of utmost importance where sound is propagated through a surface duct. A change in gradient of .2 °C per 30 meters can be the difference between an excellent duct with good ranges and no duct and poor ranges.

Horizontal velocity gradients in the ocean are not as great as those in the vertical; however, they can completely destroy a duct if they occur between the sound source and the target.

Bottom composition and roughness control, to a large extent, the reflective and absorbent capabilities of the bottom. Shallow-water sediments are quite diverse. Areas of mud, sand, mud-sand, gravel, rock, and coral are not uncommon over shelf regions.

In shallow water, as in deep water, the sound velocity profile controls the degree of refraction of sound rays. For an example of how similar profiles effect shallow- and deep-water transmissions, consider the following:

In deep water, where a strong negative gradient exists, sound rays are refracted downward and result in shadow zones. On the other hand, in shallow water the downward refracted rays bounce off the bottom, travel upward, and bounce off the sea surface. This process continues until the shadow zone is completely insonified. Consequently, this results in better detection probability.

DEEP-WATER TRANSMISSIONS.—In deep water, sound may travel from and to a sonar via surface duct, convergence zone, bottom bounce, and sound channel transmission paths. Figure 2-2-4 illustrates the deep-water sound-transmission paths.

Surface Ducts.—Surface ducts occur in deep water just as they do in shallow water.

Sound Channels.—A sound channel is formed when a negative-velocity gradient overlies a positive-velocity gradient. The thermal gradient necessary to produce a sound channel is negative over isothermal or negative over positive. The sound channel axis is found at the point of sound-velocity gradient change. The axis is the point of minimum sound speed. Sound channels trap sound rays and provide extremely long ranges. Such thermal conditions are found in shallow and deep water.

Shallow sound channels are found in the near-surface layer. They are rare and transitory (they move), and occur when thermal conditions are unstable (cold water over warm). In the Pacific Ocean, shallow sound channels are most common in the area north of 40°N between Hawaii and the continental United States. In the Atlantic, they are most frequently observed in the vicinity of the Gulf Stream.

Deep sound channels are far more prevalent than their shallow counterpart. In the deep ocean, temperature generally decreases with depth (the main thermocline). This produces a negative-velocity gradient and sound rays that refract downward.

In the Atlantic, such gradients exist to a depth of approximately 700 fathoms. Below 700 fathoms, the gradient becomes isothermal. In the Pacific, the isothermal layer begins around 500 fathoms. Below these depths, the greater pressure combines with the isothermal-temperature gradient to produce a positive-velocity gradient. The sound rays are refracted upward. The depth of the gradient change is known as the deep-sound-channel axis. The deep-sound-channel axis varies from 1,225 meters in the mid-latitudes to near the surface in the polar regions.

Extremely long sonar ranges (on the order of thousands of miles) are possible within a deep sound channel. Deep sound channels are also known as SOFAR channels.

Convergence Zone.—This sound transmission path is based on the principle that sound energy from a shallow source travels downward in the deep ocean and is refracted at depth. The refracted rays travel upward and reflect off the surface about 30 miles from the sound source. The reflected rays travel downward, and the pattern repeats itself. The sound rays reappear in the surface layer at successive intervals of about 30 miles out to several hundred miles.

There are two conditions necessary for convergence zone transmission: (1) The sound velocity at depth must be equal to or greater than the sound velocity at the surface and (2) the water depth below the deeper sound velocity maximum must be great enough to permit the refracted sound rays to converge in a small area at the surface.

The three transmission paths just discussed depend upon the restrictive conditions of the velocity profile and the depth of the sound source and receiver. Thus, if velocity gradients are ignored, path predictions are not possible. The fourth path can be predicted roughly without considering gradients. This path is the bottom reflected path, commonly termed bottom bounce.

Bottom Bounce.—Bottom bounce transmission uses angled ray paths to overcome velocity gradient changes. The sound energy is directed downward at an angle. With steeply inclined rays, transmission is relatively free from thermal effects at the surface, and the major part of the sound path is in nearly stable water. The sound energy is affected to a lesser degree by velocity changes

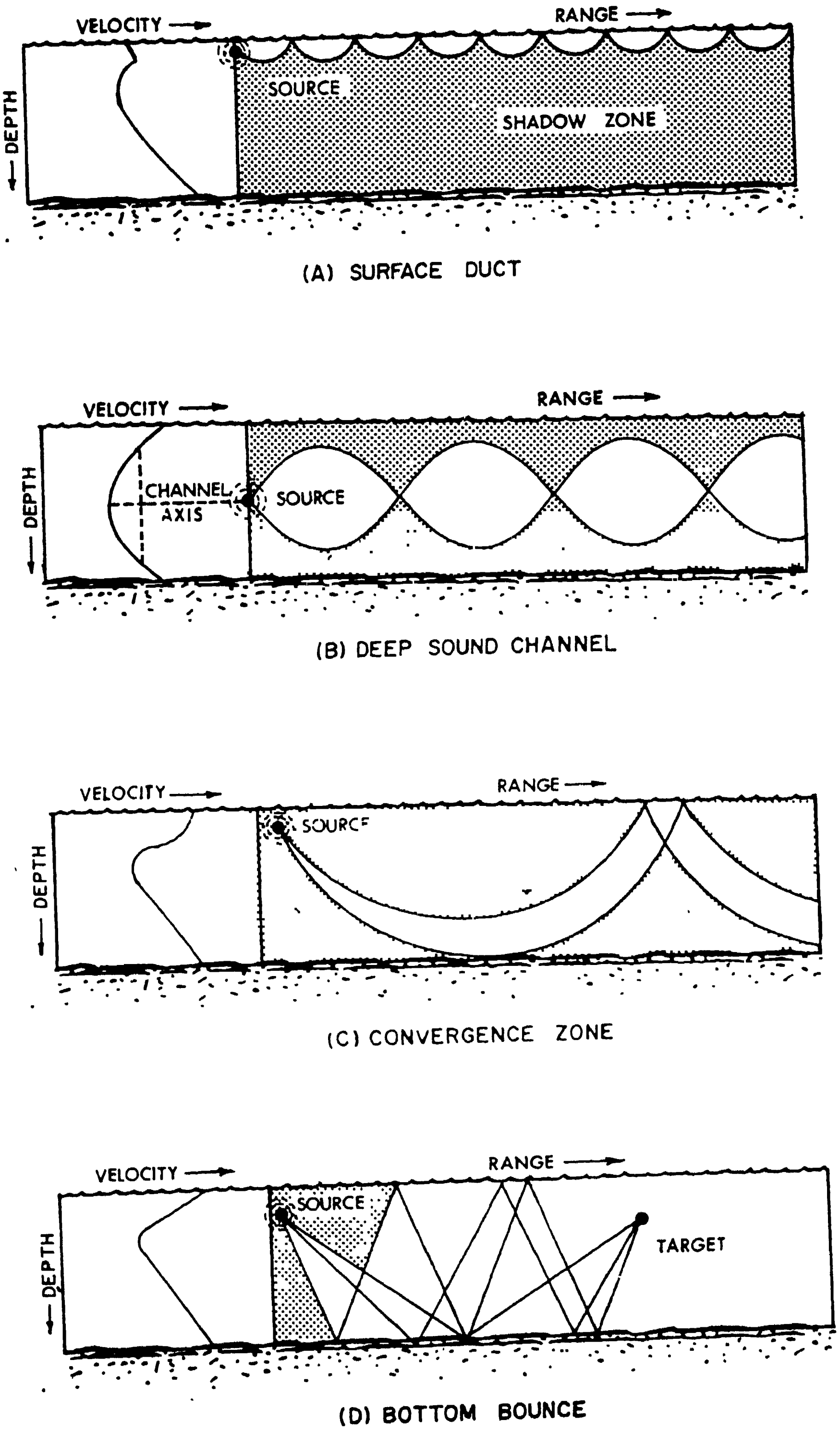

Figure 2-2-4.—Deep-water sound-transmission paths.

than the more nearly horizontal ray paths of other transmission modes.

Long ranges can occur in water deeper than 1,000 fathoms, depending on the bottom slope. It is estimated that 85% of the ocean is deeper than 1,000 fathoms, and bottom slopes are generally less than or equal to 1 degree. On this basis, relatively steep angles can be used for single bottom reflection to a range of approximately 20,000 yards. At shallower depths, multiple bounce paths develop which produce scattering and its high intensity energy loss.

Learning Objective: Define and differentiate between the elements used in the active and passive sonar equations.

Active Sonar Equation

In determining ranges of active sonar transmissions, scientists use mathematical equations. The active sonar equation takes two forms: Active sonar performance may be noise- or reverberation-limited, depending on the dominant type of background interference. When the dominant background is self noise, the active sonar equation may be written as follows:

$$SE = SL + TS - RD - NL + DI - 2\ PL,$$

where SE = Signal or echo excess

SL = Source level

TS = Target strength

RD = Recognition differential

NL = Noise level

DI = Directivity index

2 PL = Two-way propagation loss

When reverberation dominates, the equation may be written

$$SE = SL + TS - RD - RL - 2\ PL,$$

where SE = Signal excess

SL = Source level

TS = Target strength

RD = Recognition differential

RL = Reverberation level

2 PL = Two-way propagation loss

SIGNAL EXCESS.—Signal excess is the amount of sound energy received from a target over and above the amount required to detect it. Signal excess is based on probability conditions. When the signal excess is zero, the probability of target detection is considered to be roughly 50%. Signal excess, like all of the other factors of the equation, is expressed in decibels.

SOURCE LEVEL.—Source level of the sonar projector pertains to the intensity of the radiated sound, in decibels, relative to a reference intensity. Source level is controlled by the design, maintenance, and mode of operation of a sonar.

RECOGNITION DIFFERENTIAL.—Recognition differential pertains to a sonarman's ability to differentiate target noise from background noise. It is a function of target design, maintenance, and a target's mode of operation. Recognition differential was originally defined as the signal-to-background-noise ratio required at the receiver to recognize a target 50% of the time. However, using the 50% probability resulted in too many signals being classified as targets that were not targets. The inordinate amount of false alarms led to a more specific qualification of RD. Today, RD can apply to a specific probability of detection (50% or some other percentage) and a specified probability of a false alarm.

TARGET STRENGTH.—The target strength of a reflecting object is the amount by which the apparent intensity of sound scattered by the object exceeds the intensity of the incident sound. This value depends on the size, shape, construction, type of material, roughness, and aspect of a target, as well as the angle, frequency, and waveform of the incident sound energy.

NOISE LEVEL.—Noise level pertains to ambient noise and self-made noise at the location of the sonar. Noise level is a function of the environment and ship's speed.

PROPAGATION LOSS.—Propagation loss is the loss of signal strength (intensity) between the sonar and the target. In the active sonar equation, PL is a two-way loss of energy, since sound energy travels out from the transmitter and back to the receiver. Propagation loss in water depends on the following factors:

1. Spreading of the sound wave front. The farther the sound wave moves from the source,

the greater the size of the wave front and the spreading of the sound energy.

2. Conversion of the mechanical energy in a sound wave to heat (attenuation).

3. Scattering due to surface, bottom, and suspended particulate reflections.

4. Leakage of sound energy from layers of trapped sound (ducts and sound channels) and leakage of energy into areas where it is absorbed and is not capable of target detection (shadow zones) is known as diffraction loss. Velocity gradients that result in ducts and shadow zones cause this loss of energy.

5. Multiple path interference. When one or more sound paths change with time, intensity fluctuations occur.

DIRECTIVITY INDEX.—Directivity is a function of the dimensions of a sonar's hydrophone (receiver) array, the number and spacing of the hydrophones, and the frequency of the received acoustic energy. These functions enable the direction of a received signal to be determined. Directivity also reduces noise arriving from directions other than that of the target. The directivity index pertains to a sonar's ability to discriminate against noise. It is defined as the signal-to-noise ratio (in decibels) at the terminals of a hydrophone array or a directional hydrophone, relative to the signal-to-noise ratio of a nondirectional hydrophone. Thus defined, DI is always a positive quantity in the equation.

NOTE

DI is not included in the reverberation-limited equation, because hydrophone directivity cannot distinguish against reverberations.

REVERBERATION LEVEL.—Reverberation is observed at the sonar receiver. The level of reverberation is a function of source level; range; and surface, volume, and bottom reverberation. When an active sonar is reverberation limited, RL is used in the equation in place of NL and DI.

Passive Sonar Equation

In passive-sonar operations, the hydrophones pick up sounds generated by a multitude of sound sources. Sonarmen must differentiate between sounds generated by a target and interfering background noise. This process is best described in what is known as the passive sonar equation. The passive form of the sonar equation, like the active form, is written using several different symbols to represent the equation parameters. One form of the equation is as follows:

$$SE = SL - RD - NL + DI - PL,$$

where SE = Signal excess

SL = Source level

RD = Recognition differential

NL = Noise level

DI = Directivity index

PL = Propagation loss

SIGNAL EXCESS.—Signal excess has the same meaning in the passive equation that it does in the active equation.

SOURCE LEVEL.—Source level pertains to target-radiated noise. It is the amount of sound energy generated by a target. The level of energy reaching the sonar receiver depends on the type of target and its mode of operation. Source level is a function of frequency, speed, depth, and target aspect. The latter refers to a target's orientation in relation to the sonar receiver.

RECOGNITION DIFFERENTIAL.—RD has the same meaning as in the active sonar equation.

NOISE LEVEL.—The definition for NL in the passive equation is the same as in the active equation. Passive sonars may be ambient-noise or self-noise limited. These sonars lessen the noise in certain frequency ranges, thereby permitting a target signal to be more readily detected.

Ambient Noise.—Ambient noise is that part of the total background noise created by

surface-ship traffic, wave action, precipitation, ice, and certain forms of marine life.

Self Noise.—Self noise is that part of the total background noise attributable to the sonar equipment, the platform on which it is mounted, or the noise caused by the motion of the platform. The major classes of self-noise are machinery noise, propeller noise, and hydrodynamic noise. The latter results from the flow of water past hydrophones, supports, and the hull structure of the platform.

DIRECTIVITY INDEX.—DI has the same meaning as in the active sonar equation.

PROPAGATION LOSS.—PL has the same meaning as in the active sonar equation except that with passive sonar, the energy loss is one-way.

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Fleet Oceanographic and Acoustic Reference Manual, RP-33, Naval Oceanographic Office, July 1986.

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UNIT 3

SATELLITE IMAGERY OF OCEANOGRAPHIC FEATURES

FOREWORD

Satellite imagery is being used more and more in oceanographic analysis. The use of infrared imagery is especially helpful in analyzing sea-surface temperature patterns, which in turn permit us to locate and distinguish features such as oceanic fronts, eddies, and areas of upwelling. I will not discuss every oceanographic feature visible in satellite imagery, but I will cover the major features. For a more in-depth discussion of oceanographic features as observed via satellite, I recommend that you read volume 2 of the *Navy Tactical Applications Guide - Environmental Phenomena and Effects* (NEPRF Technical Report 77-04).

UNIT 3—LESSON 1

SATELLITE IMAGERY OF OCEANOGRAPHIC FEATURES

OVERVIEW

Identify oceanographic features seen in satellite imagery.

OUTLINE

Oceanic fronts

Eddies

Upwelling

Internal waves

Sea ice

SATELLITE IMAGERY OF OCEANOGRAPHIC FEATURES

Using satellite imagery to detect oceanographic frontal bounderies, eddies, etc., has made our job as Aerographer's Mates in the world of ASW easier than in the past. Many features were missed in the past because of the lack of reports or poor analyis, and many sonar-related problems could not be adequately explained based on past charts. Observing the oceans through the eyes of satellites provides for far greater coverage of oceanic features and greater accuracy in the location and movement of these features.

Learning Objective: Differentiate between permanent and transient oceanic fronts, and recognize the differences that occur across frontal boundaries.

OCEANIC FRONTS

The mean surface positions of the major oceanic frontal systems of the world are depicted in figure 3-1-1. You will note that most of the fronts are located along the boundaries of surface oceanic currents. These fronts are termed "permanent", because they are observed during all seasons in the same general geographic location. These fronts do not move significantly from their mean position. Oceanic fronts that are comparatively short lived and show considerable variation in location are termed "transient". Such fronts may exist from a few days to several months. They are primarily the result of seasonal water changes, regional upwelling, open-sea convergences and divergences, pronounced surface heating or cooling, or river runoff.

Oceanic fronts separate water masses of different densities, and since the density of seawater is a function of temperature and salinity, there are thermal (temperature) fronts and haline (salinity) fronts. Oceanic fronts are found in the upper layers of the oceans in areas of pronounced horizontal temperature and/or salinity gradients. One such area is off the east coast of the United States where the Gulf Stream interacts with the much cooler coastal waters and the cold Labrador current.

The Gulf Stream front is located in the region of the sharply defined thermal gradient that exists between the Gulf Stream water and the coastal waters. A typical vertical cross section of

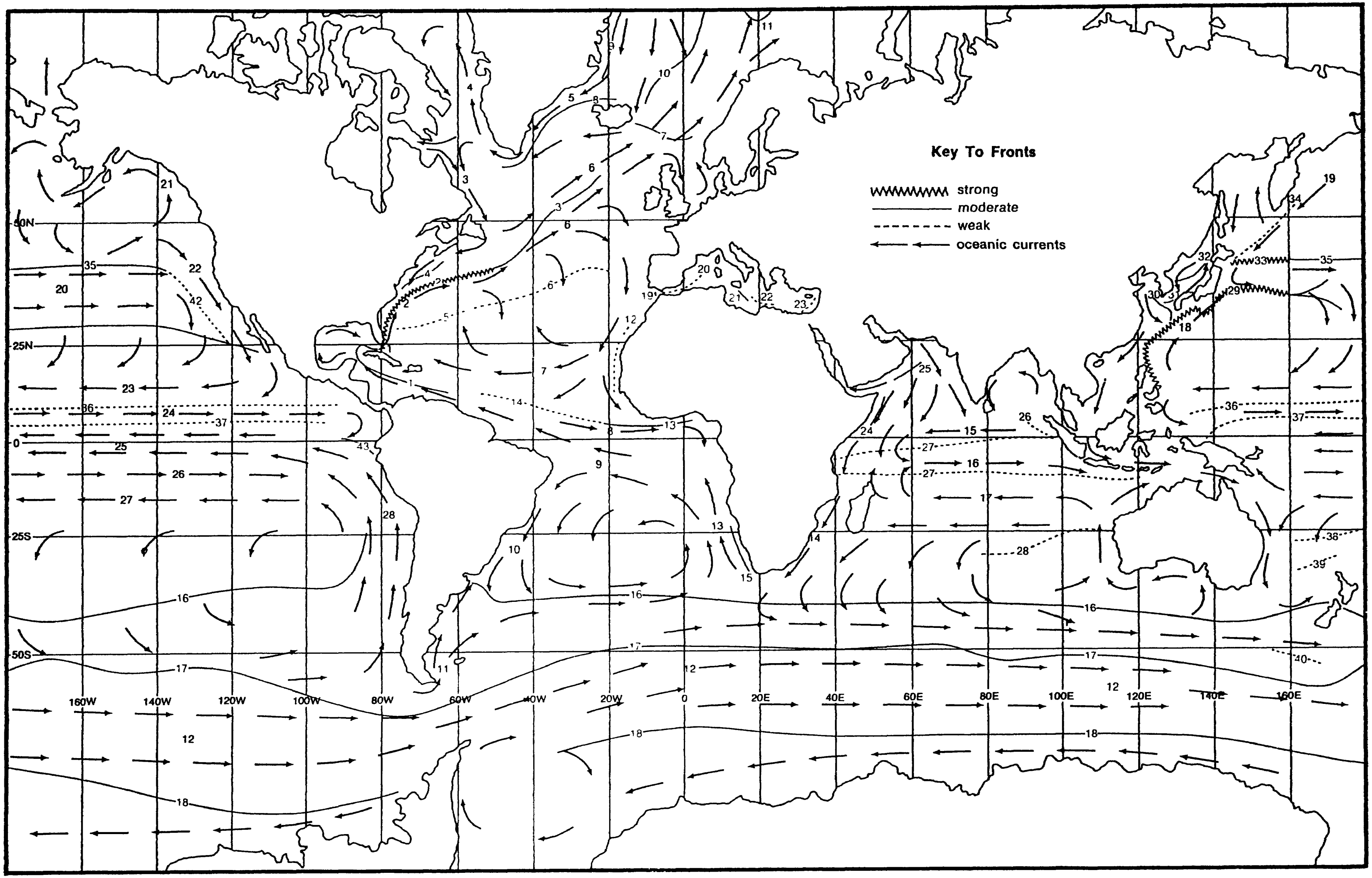

Figure 3-1-1.—Mean surface positions of the major oceanic frontal systems of the world.

emperature across the Gulf Stream during spring s shown in figure 3-1-2. Note the sharp vertical emperature gradient on the coastal side of the Gulf Stream. The persistence of this gradient has given rise to the term *north wall* to describe this portion of the Gulf Stream. The north wall, as revealed by the temperature contrasts in satellite magery, delineates the surface synoptic location of the Gulf Stream frontal system. In addition to he temperature and/or salinity differences across oceanic fronts, there may be differences in water color, wave height, and current velocity.

Oceanic fronts and currents can be monitored n infrared satellite imagery. Temperature differences across the frontal zones produce distinct gray shade patterns which reveal the frontal systems, including meanders and eddies. Regions of upwelling, river runoff, and current boundaries can also be distinguished in imagery hrough gray shade differences. Figure 3-1-3, an nfrared picture taken in March 1988, shows the shades of gray associated with the thermal contrasts along the eastern coast of the United States.

Distinguishing oceanic features in visual magery is far more difficult than it is in infrared magery. It is possible to distinguish a front that ies in an area of sunglint if the difference in sea tates across the front is strong enough to produce ight and dark shading in the frontal zone.

It is important to recognize that the oceanic frontal features seen in satellite imagery are those of the oceans' upper layers only. Just as meteorological fronts extend upward into the atmosphere, oceanic fronts extend downward into he ocean. For example, fronts associated with major currents often extend to considerable depth (Gulf Stream 3,300 ft; Kuroshio 2,300 ft), while fronts formed by surface heating and cooling or river runoff are quite shallow (165 ft, or less). Below the surface across these fronts, there may be differences in light transmission, dissolved chemicals, biological population, and sound velocity propagation. The latter two are very important in sonar applications.

Knowledge of oceanic fronts is extremely important in submarine and anti-submarine operations, as they are the basis of many tactical decisions.

Learning Objective: Identify the two types of oceanic eddies and the type of satellite imagery used to locate and differentiate between them.

EDDIES

Oceanic eddies are distinct, closed cyclonic or anticyclonic circulations. Cyclonic eddies are generally cold core, while anticyclonic eddies are generally warm core. But if the temperature of the water increases as you move outward from the center of an eddy, the eddy is cold cored (coldest temperature at the center), regardless of the circulation.

Eddies are formed in several different ways. They can develop when a meander in a major ocean current becomes very large and gets cut off from the main current. Such formations are similar to the cut-off highs and lows that occur

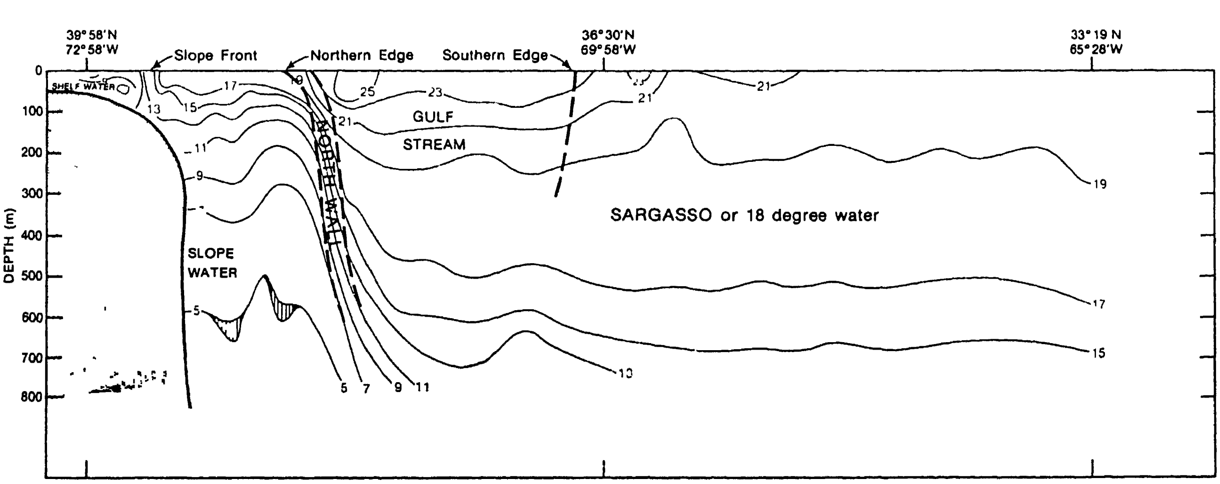

Figure 3-1-2.—Typical temperature profile across the Gulf Stream during spring.

in the primary circulation patterns found in the atmosphere. These eddies have diameters that range between tens of miles to hundreds of miles and, like the currents that form them, their circulations are strongest near the surface. Eddies are also produced by the deflection and/or channeling of an ocean current by the shape of the coastline and the topography of the ocean bottom. Small eddies (tens of miles in diameter) have also been observed to form from the intrusion of one water into another. The intruding water bends back towards itself, forming a small rapidly rotating eddy.

The surface-temperature patterns of oceanic eddies are visible in infrared satellite imagery. The temperature differences across eddies produce gray-shade differences. Figure 3-1-4 shows eddies formed by meanders within the Gulf Stream.

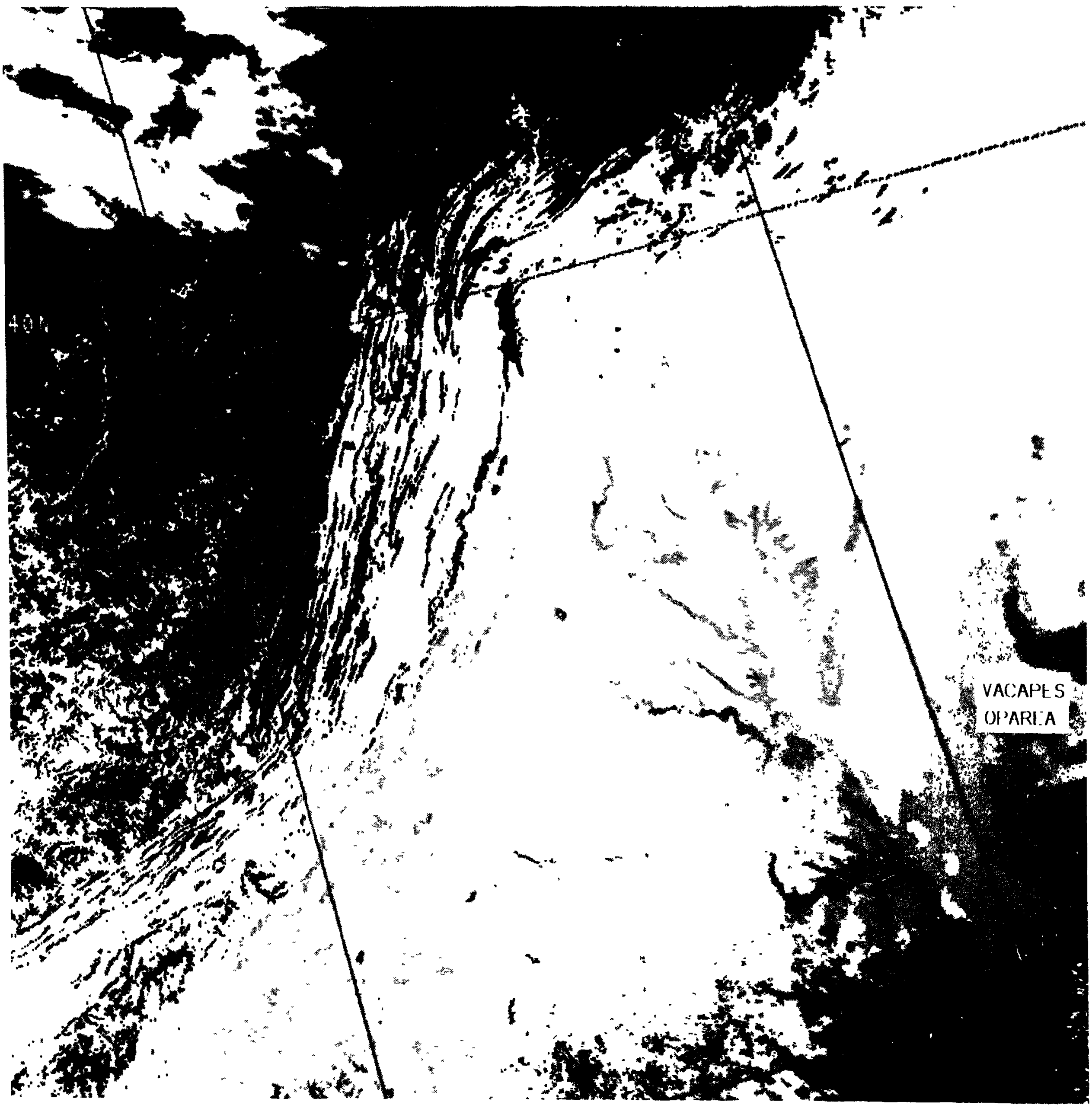

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Figure 3-1-3.—An infrared picture showing shades of gray associated with thermal contrasts along the eastern coast of the United States.

305.2

Figure 3-1-4.—An enlarged view of a VHRR infrared picture showing anticyclonic eddies formed from shoreward meanders of the Gulf Stream.

Cold eddies are often partially encircled by a convective cloud line at their edge, while convective clouds may form directly over warm eddies. Cold eddies act as an atmospheric stabilizer by cooling the air directly overhead, thereby slowing the movement of stronger winds aloft toward the surface. Thus, there is a tendency for the seas in cold eddies, and cold water in general, to be less rough than the surrounding warmer waters. Eddies are also used tactically by submarines because of the sound propagation differences that exist inside and outside these circulations.

Learning Objective: Identify thermal patterns created by upwelling.

UPWELLING

Upwelling in a body of water is a process by which subsurface water rises toward the surface. Since water temperature generally decreases with depth, the upwelled water is colder than the surface water it replaces. Thus, sea-surface temperatures are characteristically lower in areas of upwelling. Infrared imagery provides information on the position and strength of the surface thermal gradients associated with upwelled water. The gray-shade patterns may appear as bands of lighter gray shades (colder temperatures) extending along coastlines. The pattern may also show plumes of cold water or cold eddies intruding into the warmer waters further offshore. See figure 3-1-5.

Learning Objective: Recognize how internal waves may be detected using satellite imagery.

INTERNAL WAVES

Internal waves are a wave phenomena in the ocean that forms between subsurface layers of

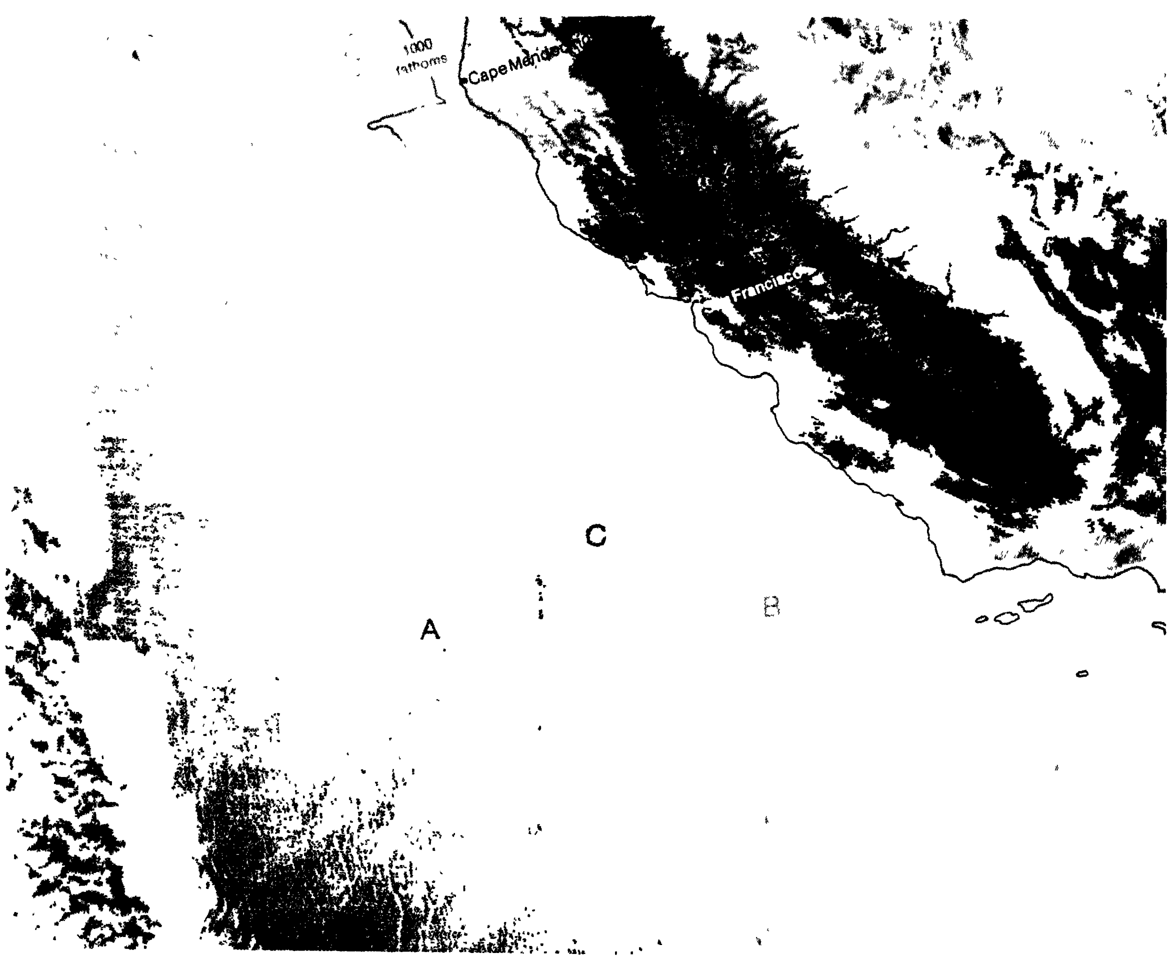

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Figure 3-1-5.—Upwelling as determined from thermal features in the California Current.

water of varying density. In the open ocean, internal waves are frequently found along the main thermocline in the layer of strong vertical temperature gradient found below the surface mixed layer.

Internal waves can have a disruptive influence on underwater sound propagation and must be identified, located, and interpreted for effects on naval undersea operations.

Internal waves cannot be directly observed from satellite platforms. However, they can be indirectly detected at the surface in visual imagery. In areas of nearly calm winds and seas and where sunglint patterns are present, distinctive alternate bright and dark bands in the sunglint area indicate the presence of internal waves. Figure 3-1-6 is an enlarged view of such an occurrence.

Learning Objective: Identify methods used to differentiate sea ice from clouds and snow covered terrain as seen in satellite imagery.

SEA ICE

The detection and monitoring of sea ice conditions is of vital importance to ships operating

305.4

Figure 3-1-6.—A sunglint area showing alternate bright and dark bands, indicating the presence of internal waves.

at higher latitudes. Icebergs, calved off ice shelves, and ice floes can pose a danger to ship operations, while the growth and extent of pack ice can impact fleet and support functions. In addition, sonar performance is degraded at the edges of and under ice fields, as sound is scattered and reduced in strength by the ice.

Distinguishing sea ice from clouds or snow-covered terrain is a primary problem in interpreting satellite imagery. In visual imagery, sea ice often has a granular structure, and leads of open water are frequently observed within ice fields. Fields of sea ice are also relatively conservative. That is, they do not change much from day to day. Clouds, on the other hand, seldom retain the same shape or remain in the same location for more than a few hours. Knowledge of the geography and climatology of a region is most helpful in identifying areas of sea ice.

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UNIT 4

METEOROLOGICAL AND OCEANOGRAPHIC PRODUCTS AND THEIR INTERPRETATION

FOREWORD

Today's Aerographer's Mates use vast amounts of meteorological and oceanographic charts and messages. All of these products contain valuable information. The charted products display information with numbers, symbols, lines, and shaded areas on a map background. Messages may either present information in plain language, abbreviated language, code, or alpha-numeric plots. As an Airman, you learned how to decode, or interpret, many different types of observation messages while studying to become a Meteorological Technician (Observer/Plotter). As an Aerographer's Mate Second Class, performing the duties of an Analyst/Forecaster Assistant, and later as an Analyst/Forecaster, you will be required to interpret information presented in many different types of charts and messages. In this unit, we will present information that will help you to interpret the meteorological and oceanographic messages and charts most frequently used by Navy Analyst/Forecasters.

In Lesson 1 we will discuss the meteorological and oceanographic models used by the computers at the Fleet Numerical Oceanography Center (FNOC), Monterey, California. In Lesson 2, we will discuss the major meteorological and oceanographic products available from the FNOC computers. The major numerical models in use by the National Weather Service (NWS) and the products available from NWS are discussed in Lesson 3. Lesson 4 addresses the Terminal Aerodrome Forecast Code (TAF). In lesson 5 we discuss products available from the Tactical Environmental Software System (TESS), and the Optimum Path Aircraft Routing System (OPARS) products are discussed in Lesson 6.

UNIT 4—LESSON 1

FLENUMOCEANCEN ANALYSIS MODELS

OVERVIEW

Identify FLENUMOCEANCEN environmental analysis models and analysis techniques.

OUTLINE

Surface analysis model

Upper-air analysis model

Scale and Pattern Separation model

Frontal analysis model

Tropopause height analysis model

Freezing-level analysis model

Expanded Ocean Thermal Structure (EOTS) analysis model

Thermodynamic Ocean Prediction System (TOPS) Coupled EOTS (TEOTS) analysis model

Ocean Frontal analysis model

Ocean wave analysis model

Sea Surface Temperature analysis model

FLENUMOCEANCEN ANALYSIS MODELS

There are many computer-generated surface, upper air, and oceanography products available from the FLENUMOCEANCEN. You should be aware of the available products, have an understanding of how they are derived, and how they are interpreted.

The heart of computer-generated environmental products is the model or program used to produce the products. Environmental models are used in analyses, prognoses, and special programs, and they are constantly being updated or refined to produce the best possible product.

Learning Objective: Recognize the impact of grid-point spacing on computer-generated analyses, and identify the parameters and the analysis technique used in FLENUMOCEANCEN's surface analysis model.

SURFACE ANALYSIS MODEL

The FLENUMOCEANCEN surface analysis model produces hemispheric and regional analyses of sea-level pressure, wind, and sea-surface temperature on grids. For example, a hemispheric

analysis is produced on a 63 by 63 grid, and a regional analysis uses a 125 by 125 grid.

Grids

Grids come in various shapes and sizes. The grid-point spacing for hemispheric products is equivalent to approximately 320 kilometers, whereas that for regional products is equivalent to 20 to 80 kilometers. The grids used in regional analysis are known as fine-mesh grids. All computer calculations are performed at the grid points, and normally, the closer the grid-point spacing, the more accurate the analysis, depending on the accuracy of the input data.

Each grid-point is assigned a value of the parameter being analyzed. For example, in a sea level pressure (SLP) analysis, each grid point is assigned an SLP. The value assigned to a grid point may be based on past history, current observations, gradient extrapolation, and/or any combination of these three variables. This process is part of the analysis technique used by the model.

Fields By Information Blending

The surface analysis model currently used by FLENUMOCEANCEN uses an analysis technique known as *Fields by Information Blending* (FIB). FIB has six component operations as follows:

1. First-guess field preparation of initialization
2. Assembly of new information
3. Blending for the parameter
4. Computing the reliability field of the blended parameter
5. Reevaluation and lateral rejection
6. Reanalysis

FIRST GUESS.—The first guess is an estimate of what an analysis will look like without considering current data. It is normally a blend of (1) the previous analysis extrapolated forward to analysis time, (2) a prognostic chart verifying at analysis time, (3) persistence from the previous analysis, and (4) climatology.

The first-guess provides continuity in data-sparse areas and gives an estimate of the shape (gradients, curvature, etc.) of the data field. In data-sparse areas, the accuracy of a final analysis depends partly upon the first-guess accuracy. The first-guess field is also useful in keeping "impossible" observations from being used in the analysis.

ASSEMBLY OF NEW INFORMATION.—In this step, reports of the parameter being analyzed, that is, pressure, wind, etc., are placed at their proper geographic positions on the grid. These observations are then compared to the first-guess values. If an observed value differs from a first-guess value by a pre-set limit, the observed value is termed "impossible" and is thrown out.

There is an inherent problem with the assembly step. The majority of the oceans are data sparse. When observations in an area are non-existent or are termed impossible, the model bases the analysis of the area on the first-guess data field. If the first-guess data field in the area is in error, the analysis ends up in error. Such errors are especially evident when atmospheric changes take place in an explosive manner. For example, if the model does not have an SLP observation(s) in an area undergoing rapid deepening or if it discards a report or reports in an area as impossible, the first-guess values are used. If the first-guess values in the area do not reflect explosive deepening, the area will be incorrectly analyzed. Any incorrectly analyzed region should be brought to the attention of the FLENUMOCEANCEN duty officer in order that the analysis can be corrected. Such corrections often require the insertion of a *bogus* report(s) into the data field. These made-up reports are designed to correct the analysis in a region in question.

BLENDING.—Blending is the model step that corresponds to the drawing of isolines by hand. To cover data-sparse regions, grid-point values are adjusted and spread to surrounding grid points using gradient knowledge and mathematical gradient formulation. Blending spreads the data from high reliability grid points (grid points with values based on observations) to those having lower reliability (grid points based on the first-guess analysis). The degree of spreading is increased with higher reliability in the gradient.

COMPUTING RELIABILITY FIELD OF THE BLENDED PARAMETER.—In this step, the computer assigns weight factors to the blended grid-point values. The higher the weight factor, the higher the reliability of the value. For example, a grid-point value based on an observation(s) normally has a higher weight than a grid-point

value based on an extension of a gradient. The reliability of all grid points is increased through the blending process.

REEVALUATION AND LATERAL REJECTION.—In step 5, FIB uses the blended parameter field and the weighted values to reevaluate each piece of information entered into the analysis. Reevaluation is a quality control done on each observation. A statistical value is computed for each report and is compared to the actual value. The statistical value measures how accurate a report really is compared to its expected accuracy as given by its assigned weight factor.

The lateral rejection check takes place when each grid-point value, with its weight, is removed individually from the grid and compared with what remains, or the "background." If the report is within its expected reliability range, no change is made to its weight. If the value is greater than the expected range but within some upper limit, its weight is reduced. If the value exceeds the range limits, the report is rejected (that is, its weight becomes zero) and it has no effect when the next assembly and blending is done.

REANALYSIS.—After the grid-point values are reevaluated and new weights are assigned, the reanalysis step begins. This step is no more than a repeat of the assembly step, using the first-guess field and the reevaluated data. The new field may be reevaluated and reanalyzed two or three times before the computer accepts it and sends it to the output section, where it is stored for transmission and for input into other programs.

Learning Objective: Identify other models and products to which FIB is applied.

FIB Applications

The FIB technique is also used with the Navy Operational Regional Atmospheric Prediction System (NORAPS) model. It is applied to FLENUMOCEANCEN's fine-mesh grids.

NAVY OPERATIONAL REGIONAL ATMOSPHERIC PREDICTION SYSTEM.—As of this writing, NORAPS is used in operational data runs to provide 36-hour fine-mesh forecasts for four geographical regions: the Mediterranean Sea, western Pacific Ocean, Indian Ocean, and the northwestern Atlantic Ocean. The Med and WestPac regions are run at approximately 03Z and 15Z, while the Indian Ocean and NW Atlantic regions are run at 07Z and 19Z. Data from two other regions are also run through the NORAPS program: the Eastern Pacific and the North Pole. However, these two regions are available to the Fleet only upon request. The number and time of NORAPS model runs changes with changing Fleet requirements.

FINE MESH ANALYSIS AND PROGNOSIS.—Fine-mesh products incorporate a terrain disassociation parameter so that values and their gradients do not unduly influence each other on opposite sides of mountains or land features. For example, cold air that piles up on the north side of the Alps does not carry over to the south side.

SST analyses for selected regions of the Gulf Stream, Labrador, and Kuroshio currents are conducted using 1/8 size fine-mesh grids. The disassociation parameter is also applied to these analyses, because the temperature structure on opposite sides of peninsulas, etc., can be markedly different.

SPHERICAL SURFACE PRESSURE AND WIND ANALYSIS.—FIB is also used in the construction of the spherical surface pressure and wind analysis. This analysis is produced on a spherical grid every 6 hours. It is a combination of a surface pressure analysis and a wind analysis. The input data include ship reports up to 6 hours old, land reports, with islands receiving more relative weight; low-level satellite winds decreased by 20% of their estimated value (satellite-derived winds are used in the area between 20°N and 20°S only); and coded isobaric analysis messages from various Southern Hemisphere meteorological organizations.

The FIB-produced Northern and Southern hemispheres sea-level pressure analyses are interpolated onto a spherical grid, and a first-guess analysis is produced for the regions poleward of 20°N and S. The first-guess pressure analysis is then blended with climatology and the previous spherical pressure analysis to produce a pressure analysis of the region equatorward of 20°N and S.

The first-guess wind analysis for mid-latitudes is derived from the surface-pressure analysis; the first-guess wind analysis for the tropics is obtained by blending the previous wind analysis with

climatology. A global marine wind analysis is performed to blend the mid latitude and tropical wind fields together.

Optimum Interpolation Technique

The FIB technique will be replaced in the near future by an Optimum Interpolation (OI) technique. The OI technique is an objective analysis methodology widely used in meteorological and oceanographic applications. It differs from the FIB technique in that it is based upon the concept that the results of the interpolation process must contain the same statistical field properties, that is, time and space statistical structure of variability, independent of the density of observations.

Learning Objective: Name the FLENUMOCEANCEN model used to analyze upper-air data and recognize why the program is run every 6 hours.

UPPER-AIR ANALYSIS MODEL

The upper-air analysis model is a subset of the Navy Operational Global Atmospheric Prediction System (NOGAPS). Geopotential heights, temperature, and wind are analyzed for the mandatory levels 1,000 millibars to 100 millibars.

NOGAPS Model

NOGAPS is the principal model system in FLENUMOCEANCEN's operational data runs which begin at 00Z and 12Z. It starts approximately 4 hours into a data run. NOGAPS replaced the Primitive Equation (PE) model as FLENUMOCEANCEN's primary forecast model in 1982. NOGAPS was last updated in 1986.

NOGAPS upper-air subset is run every 6 hours, even though radiosonde and rawinsonde observations are taken synoptically at 0000Z and 1200Z only. By running the program every 6 hours, off-time observations can be included in the run. This permits the inclusion of satellite data and aircraft reports, as well as off-time buoy and ship reports. This means that during any single analysis, there can be as much as a 6-hour difference in observations. The program carries the off-time data forward to analysis time. This process is referred to as *data assimilation.*

NOTE

The 0600Z and 1800Z upper-air analyses are used as a basis for the 1200Z and 0000Z data runs. They are NOT transmitted to the Fleet.

In addition to the NOGAPS-generated spherical upper-air analyses, FLENUMOCEANCEN also produces global band upper-air analyses and southern hemispheric polar stereographic upper-air analyses.

Global Band Upper-air Analysis

Winds and temperatures are analyzed on a global band grid every 12 hours. The grid is a Mercator projection true at 22 1/2° degrees latitude and extends from 40°S to 60°N. The first-guess field south of 22°N is based on persistence, reverted to climatology. This is primarily due to the sparseness of data over large portions of this region. North of 22°N, NOGAPS upper-air analysis fields are used.

Numerous types of data are used in the analysis. Conventional radiosonde and aircraft reports are used in both the wind and temperature analyses. The wind analysis also includes Pibal reports and satellite derived winds. Vertical temperature profiles obtained from satellite radiometers are used in the temperature analysis. The temperature profiles greatly increase the data base in the Southern Hemisphere.

Southern Hemisphere Polar Stereographic Analysis

This analysis uses the same technique as is used in the northern hemisphere upper-air analysis. A major difference is in the amount of satellite data used and the greater weight placed on satellite-derived 1,000- to 300-millibar thickness values.

Learning Objective: Recognize the most common charts produced using the scale and separation pattern model, and the major problem with the model.

SCALE AND PATTERN SEPARATION MODEL

The circulation at any level within the atmosphere shows features of varying scale (size) and pattern. At the surface, there are micro-lows, troughs, ridges, migratory cyclones and anticyclones, and the large-scale semi-permanent pressure systems. Aloft, there are troughs, ridges, highs, and lows with varying wavelengths and amplitudes. These in turn are all part of the still larger scale system, the planetary vortex.

Interaction of features either at the same level or at differing levels is a major problem faced by synoptic analysts and forecasters. The problem stems from distortion in the circulation patterns caused by the interaction of small-scale and large-scale features. The classical example, for instance, occurs in the vertical; the long-wave patterns are distorted by short waves. The distortion makes for subjective positioning of the long-waves, and the positions are usually inaccurate. An inaccurate analysis then leads to inaccurate prognoses. To overcome such subjective determinations, the *scale and separation* model was developed.

The scale and separation model provides an objective measure of scale while retaining characteristic recognizable patterns. It separates features of various size into separate parts. For example, it takes the 500-millibar field and separates it into a short-wave field (500-millibar SD), a long-wave field (500-millibar SL), a residual field (500-millibar SR), and a planetary vortex field (500-millibar SV). The model uses a smoothing process to separate each field. For example, if the small-scale features (SD) are smoothed out of the total field (Z), a residual field (SR) remains. The residual field contains the large-scale disturbance features (SL) and the planetary vortex (SV). The SR field at 500 millibars is ideal for locating long-wave troughs. A more massive smoothing process continues on the residual (SR) field until only the planetary vortex remains. The large-scale disturbance pattern is obtained by subtracting the planetary vortex field from the residual field (SL = SR − SV). The smoothing relationships, in the order given above, are Z − SD = SR and SR − SV = SL.

Thus, SV = SR − SL or Z − SL − SD, SL = SR − SV or Z − SV − SD, and SD = Z − SR or Z − SV − SL.

To be totally accurate, the amount of smoothing required to remove any one scale should vary depending on the time of year. However, the FLENUMOCEANCEN model employs only the October smoothing value so as not to disrupt component continuity. This results in SL features being somewhat weaker than they should be in summer, and the SD features being somewhat stronger. The reverse is true in winter.

Learning Objective: Recognize the parameter used in FLENUMOCEANCEN's atmospheric frontal model and the strengths and weakness of the final product.

FRONTAL ANALYSIS MODEL

The most desirable aspect of the FLENUMOCEANCEN frontal analysis model is its objectivity. The fact that mean potential temperature is the only parameter used to determine frontal positions makes it very objective.

Potential temperatures (θ) are obtained by calculating the 1,000- to 700-millibar thickness field and converting the thickness to the mean potential temperature of the 1,000- to 700-millibar layer. The program then computes the gradient of the mean potential temperature gradient (GG). A GG θ analysis accurately marks the division between two air masses having different thermal structures.

The least desirable aspect of the frontal analysis model is its overall accuracy. Large grid size, and the possible inaccuracy of upper-air temperature analyses over data-sparse areas precludes frontal positions from being more accurate than ± 100 miles. The program also has a few other weaknesses, as follows:

- It may indicate fronts in mountainous regions when no fronts exist.

- It handles occlusions poorly, because of the lack of thermal contrast across occluded fronts.

- It handles fast-moving cold fronts poorly, because the major temperature contrast occurs well behind the front.

- It produces false frontal indications in regions where fast-forming strong inversions develop.

For all the above reasons, GG θ frontal analyses should NOT be used as the final determination in positioning fronts. We recommend that you use the GG θ analysis as a first guess or simply as a guide in your analysis procedure. You should analyze as many frontal placement parameters as possible before settling on your final frontal positions.

Learning Objective: Recognize how FLENUMOCEANCEN models derive the heights of the tropopause and the freezing level.

TROPOPAUSE HEIGHT-ANALYSIS MODEL

The tropopause is defined by characteristic changes in the temperature lapse rate. In computing the height of the tropopause, the FLENUMOCEANCEN model combines the lapse rate between the 500- and 400-millibar levels extrapolated upward and the lapse rate between 150- and 100-millibar level extrapolated downward. The height of the tropopause is found at the point where the two lapse rates intersect. This level averages out to be 700 feet below the observed tropopause. A 5-year evaluation period of the above method also showed that, on the average, the level of maximum winds (in the jet core) is found 2,300 feet below derived tropopause heights. The model incorporates a 3,000-foot constant to account for the 700- and 2,300-foot deviations. This means a tropopause height chart actually represents the level of maximum winds. The true tropopause height is 3,000 feet higher than indicated on the chart.

FREEZING LEVEL MODEL

The freezing-level model interpolates the freezing level from the temperatures reported at the mandatory constant-pressure levels. Starting at 1,000 millibar, the computer checks the temperature at each mandatory level until it encounters the first level with a temperature below 0 °C. The model uses this level and the one preceding it to interpolate the freezing level.

There are some problems associated with this linear interpolation process. It does not account for the following: (1) poor constant-pressure height and/or temperature analyses, (2) inversions, or (3) multiple freezing levels. Even with the above limitations, interpolated heights are normally within 100 feet of observed values. The freezing-level chart is widely used in aviation forecasting. It is used to outline areas of potential aircraft icing, and in thunderstorm forecasting. The most severe icing occurs at temperatures between 0 °C and −10 °C. With regard to thunderstorms, lightning strikes are most prevalent at the freezing level. Pilots must be advised of this when their aircraft is cleared through a thunderstorm area. Freezing-level charts are also used to forecast changes from rain to snow and vice versa.

Learning Objective: Identify FLENUMOCEANCEN oceanographic analysis models and their uses.

EXPANDED OCEAN THERMAL STRUCTURE (EOTS) ANALYSIS MODEL

The EOTS model is used to produce temperature versus depth (surface to bottom) analyses, Sea Surface Temperature (SST) analyses, and layer depth analyses. EOTS provides the input for most of the acoustic predictions generated at FLENUMOCEANCEN.

Data Input

The daily real-time global data base used by EOTS consists of 150 to 200 XBT observations, 1,200 to 2,000 SST observations (ship injection or bucket), and 50,000 to 80,000 satellite SST readouts.

EOTS can also accept synthetic data inputs such as horizontal surface and subsurface thermal gradients. The regional centers supply the synthetic data in message form.

Analysis

EOTS analyzes 26 thermal parameters in the upper 400 meters of the sea on a 63 by 63 or 125 by 125 vertical grid. Below 400 meters, the thermal field is derived from climatology and is modified to blend smoothly with the temperature profile analyzed above 400 meters.

The primary layer depth (PLD) is the first parameter analyzed by the model. This is generally the depth of the seasonal thermocline. The remaining 25 parameters are temperatures and vertical temperature derivatives. They are analyzed at fixed and floating (fluctuating) levels. The floating levels are relative to the PLD: PLD-25 meters, PLD + 12.5 meters, PLD + 25 meters and PLD + 50 meters. Consequently, when the PLD changes, so do the floating levels. FIB methodology is the heart of the EOTS analysis. A three-cycle FIB technique is used to analyze the fixed- and floating-level temperatures on a horizontal plane and to analyze the vertical temperature gradients between the fixed levels. These analyses are based purely on information blending techniques. EOTS does not consider the effect of oceanic physics and air-sea interaction processes.

Learning Objective: Identify the model that couples EOTS with atmospheric processes.

TOPS-COUPLED EOTS (TEOTS) ANALYSIS MODEL

The coupling of ocean thermal analyses to atmospheric forces is accomplished via the physics incorporated in the Thermodynamic Ocean Prediction System (TOPS) model. The coupling prevents mixed-layer depths and mixed-layer temperatures from following strictly climatological trends. For example, consider a rapidly deepening low-pressure system with strong winds and heavy seas. Such a system normally produces strong mechanical mixing, which in turn produces deeper layer depths. However, if the strong winds and seas occur over an area of the ocean from which little or no ocean thermal data is received, and atmospheric conditions are NOT considered, EOTS uses the climatological mean of the layer depth in the area. In such a case, the LD would be too shallow for the existing conditions.

The TEOTS model is run once every 24 hours and is coupled to TOPS in cyclical fashion. The analysis system is exacting the same as EOTS, except for the coupling procedure and a different prescription of certain tuning parameters. Like EOTS, the FIB technique is used to combine the various types of data.

TEOTS is used to produce ocean temperature versus depth profiles and PLD analyses for oceans of the Northern and Southern hemispheres and for individual seas, that is, the eastern and western Mediterranean Sea and the Norwegian Sea.

Learning Objective: Identify the primary elements used in FLENUMOCEANCEN's ocean frontal analysis model.

OCEAN FRONT ANALYSIS MODEL

Ocean fronts separate water of different physical, chemical, and biological properties. Ocean fronts are much like atmospheric fronts in that (1) they move, but are much slower than atmospheric fronts; (2) they may be sharply defined or difficult to locate; (3) segments may be quasi-stationary; and (4) intensity changes occur with time. Prior to the ocean frontal model being developed, a large number of oceanic parameters were tried and tested to see which parameters would provide the best analysis. Salinity and biological parameters were not even considered, because of the lack of synoptic data. When all the testing was complete, FLENUMOCEANCEN settled on surface and subsurface temperatures as the parameters it would use. Like numerical atmospheric frontal analysis, a GG operator is used to describe oceanic fronts. It is applied to fine-mesh SST analyses and to fine-mesh subsurface temperature analyses. The latter are obtained in the ocean thermal structure analyses performed by EOTS.

Frontal analyses based on fine-mesh SST fields are considered very reliable. Frontal analyses

based on subsurface thermal fields are NOT considered to be overly reliable, because subsurface data inputs are drastically sparse. You should be aware of which field is used for input and know the locations of the observations used to make the field in order to evaluate the reliability of any ocean frontal analysis.

OCEAN WAVE ANALYSIS MODEL

Ocean wave analysis is conducted numerically using the Global Spectral Ocean Wave Model (GSOWM). This model came into existence in 1985 and replaced the older Spectral Ocean Wave Model in all areas except the Mediterranean Sea.

GSOWM functions are performed on the standard FLENUMOCEANCEN 2.5° latitude by 2.5° longitude spherical grid in a global band extending from 77.5°N to 72.5°S.

GSOWM directional wave spectra is used to derive the following output fields: significant wave height, maximum wave height, whitecap probability, and primary and secondary wave direction and period. These fields are transformed to a variety of map projections.

Learning Objective: Identify the model used to produce SST analyses.

SEA-SURFACE TEMPERATURE ANALYSIS MODEL

Any of the environmental models may be used to produce analyses and prognoses for ocean waves, sea-surface temperature, and ocean thermal structure. Most often, the Navy Operational Regional Prediction System (NORAPS), is used to produce regional SST analyses. The reported sea surface temperatures from ships, satellite reports, and climatology are weighted and combined for a data field. The data is then evaluated in a similar manner as any other data in the surface analysis routine.

SUMMARY

In this lesson we have discussed some of the analysis techniques used by the computers at FLENUMOCEANCEN. This information has been discussed so that you, the analyst, will have a basic knowledge of the strengths and weaknesses of the computer analyses you will be using. With this knowledge, you will be able to make informed adjustments to information depicted in FLENUMOCEANCEN's computer analyses.

UNIT 4—LESSON 2

FLEET NUMERICAL OCEANOGRAPHY CENTER METEOROLOGICAL AND OCEANOGRAPHIC PRODUCTS

OVERVIEW

Identify and interpret major meteorological and oceanographic products produced and issued by the Fleet Numerical Oceanography Center.

OUTLINE

Surface weather charts

Upper-air charts

Freezing-level charts

Oceanographic charts

Message products

Acoustic Range Prediction Products

FLEET NUMERICAL OCEANOGRAPHY CENTER METEOROLOGICAL AND OCEANOGRAPHIC PRODUCTS

The Fleet Numerical Oceanography Center (FLENUMOCEANCEN or FNOC) Monterey, California, produces computer-generated meteorological and oceanographic charts and messages for use by Naval Oceanography Command (NOC) units, the Navy, and the Department of Defense.

The data from which meteorological and oceanographic charts are derived is transmitted from FNOC to NOC Centers via the Naval Environmental Data Network (NEDN) to Naval Environmental Display System (NEDS) terminals. The NEDS units (AN/FMC-1) store the data. NEDS operators are then able to produce the charts on their NEDS terminals. They are also able to transmit any or all of this data to NOC facilities and/or detachments having a NEDS-1A unit (AN/FMC-2). The centers can also include these charts as part of their facsimile transmission schedule to the Fleet.

Many Department of Defense users other than the Navy, and other U.S. Government agencies, such as the U.S. Coast Guard and National Oceanic and Atmospheric Administration (NOAA) activities, receive FNOC charts and products via the joint Navy/NOAA Oceanographic Data Distribution System (NODDS). This system allows charts and products to be received on desk-top computers using a telephone modem.

The major benefit derived from computer-generated charts is the time saved by not having to plot and analyze the data. A major problem with these charts is that analysts and forecasters work from finished products, and do not analyze the observations used to produce the charts. A great deal of meteorological insight is lost when weather observations are not studied.

Fleet requests for products are sent to FNOC over the AUTODIN or NEDN communications networks, using the Automated Products Requests (APR) format.

Learning Objective: Interpret various surface weather charts produced by FNOC.

SURFACE-WEATHER CHARTS

Manually prepared surface-weather charts are quite different from the computer-generated

surface-weather charts. At the very least, manually produced surface charts will include weather station plots, isobars, and fronts. A more in-depth chart may contain a neph-analysis (cloud analysis), air mass designators, and a weather depiction analysis. At their best, manually produced surface-weather charts are highly colorful and extremely informative.

Computer-generated surface charts do not contain nearly as much information as the manually produced charts. They do provide an isobaric analysis; they may or may not include weather station plots or low-level-wind plots; and they do not contain fronts. Fronts must be hand-drawn on these charts.

Surface-Weather Analysis Charts

Synoptic charts of surface pressure, wind, and frontal analysis are produced every 6 hours, beginning at 0000Z. An example of an FNOC *surface-pressure preliminary analysis* (SFC PRELIM) is shown in figure 4-2-1. This chart covers about an eighth of the globe and provides an initial look at the pressure systems. Highly smoothed isobars are drawn every 4 millibars (hectopascales). High- and low-pressure centers are indicated by *H* and *L*, with the exact center

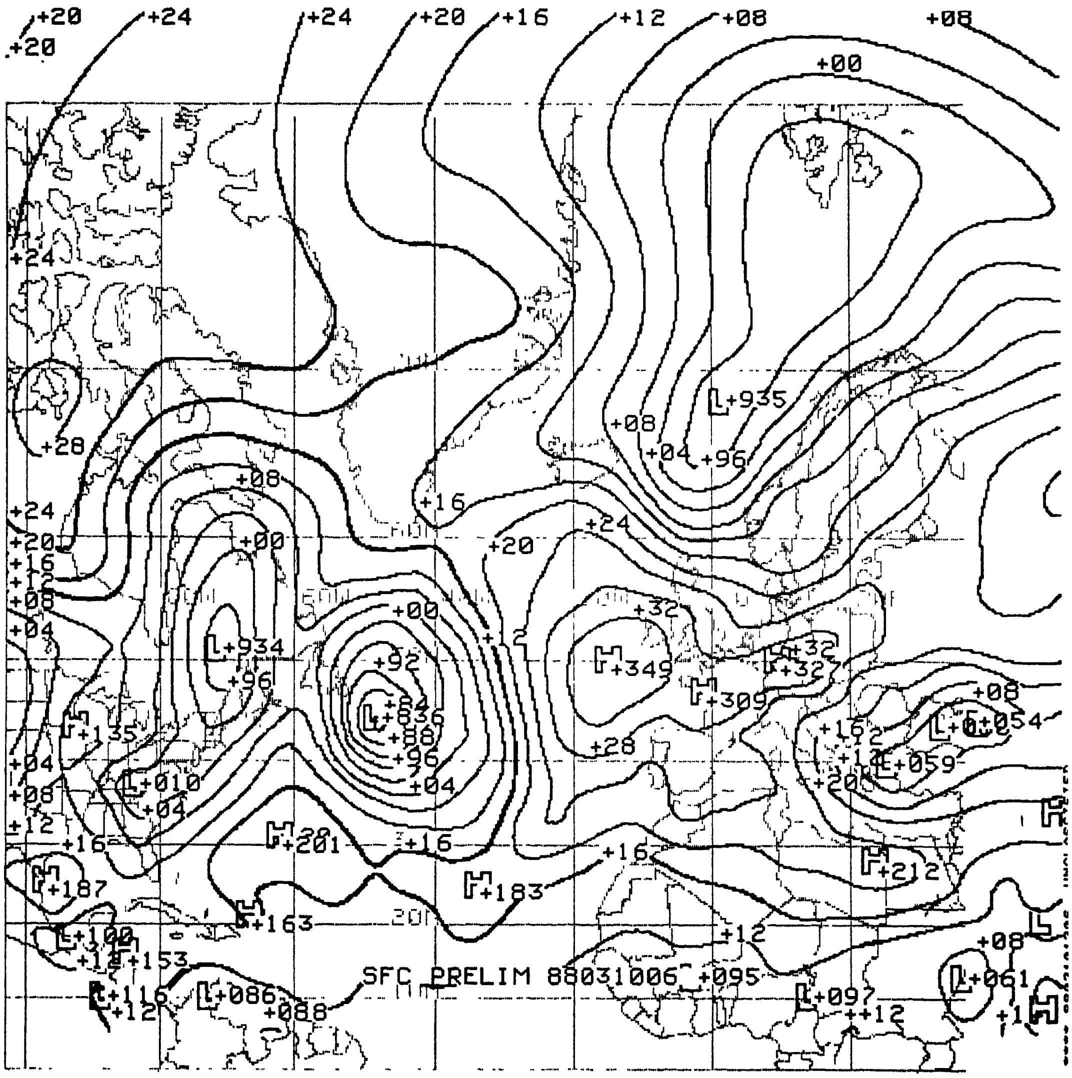


Figure 4-2-1.—Surface preliminary analysis.

indicated by a "+" mark. The central pressure is printed to the right of the "+" mark in tens, units, and tenths of millibars.

Shortly after the SFC PRELIM is produced, the computers complete the more detailed *surface pressure* and *surface wind* analyses. These two analyses are transmitted to users over the NEDN as separate data fields, and then are combined at a NEDS terminal to produce a composite chart.

Figure 4-2-2 shows a more detailed combined surface wind and pressure analysis, a Global Band tropical analysis. This Mercator map projection is typical of charts produced for users in the tropics. Note the smaller scale; this chart covers only about one-fifteenth of the globe. The isobars are drawn every 4 millibars. They show a much more detailed representation of the pressure pattern than is shown in the SFC PRELIM analysis, although smoothing may eliminate minor, yet significant pressure deviations. Winds are represented on this chart by standard wind plots on a five-degree grid. They do not represent actual reported winds, but computer-averaged winds over a five-degree-square area. Neither of the FNOC surface analyses depicts fronts or troughs.

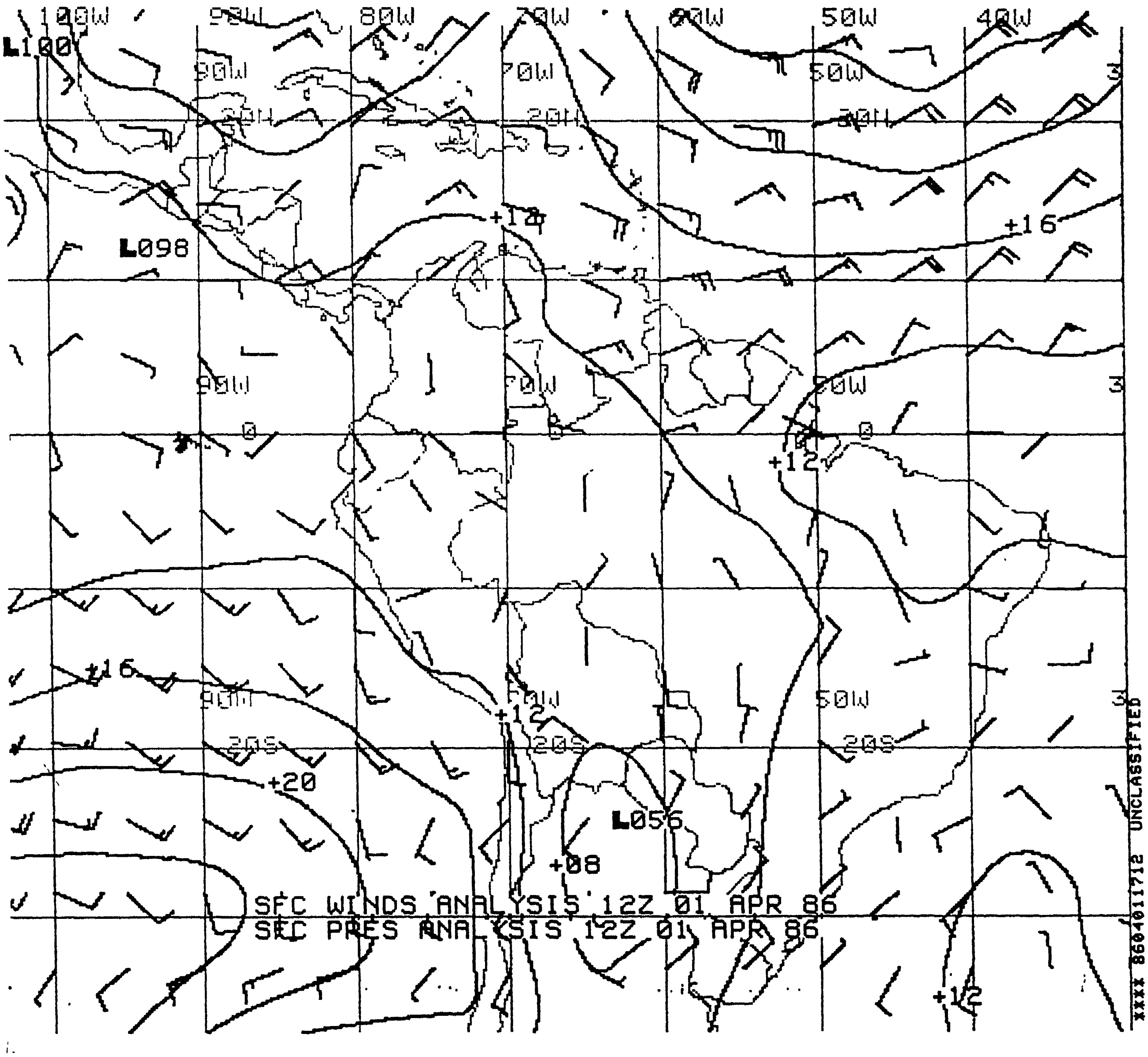


Figure 4-2-2.—Surface-wind and surface-pressure analysis.

The *frontal depiction analysis* (GG-Theta) is shown in figure 4-2-3. This example is an analysis from central Asia to central North America. The frontal positions are depicted with contours of percent probability of the frontal location. It is up to the user to determine the actual frontal placement, as well as the type of discontinuity—warm front, cold front, occlusion, or pressure trough.

This analysis does not always provide the user with clear-cut frontal boundaries. Normally, fronts are located where the isolines are packed tightly around an elongated central core. The isolines parallel all fronts except occluded fronts. The isolines lie more or less perpendicular across occlusions. Usually, the higher probabilities surround areas where reports show strong discontinuities, such as large temperature changes, large wind speed and direction changes, or marked pressure rises and falls. The higher probability areas tend to indicate the locations of the more dynamic fronts.

Notice in the tropical portion of the example (fig. 4-2-3) that several areas are surrounded by only 10-percent-probability contours. These areas indicate that the computer has found only minor discontinuities. A minor discontinuity may be a pressure fall or a wind shear line indicating a tropical wave. In the mid-latitudes, the lower probability contours may indicate a pressure trough or a very weak, non-weather-producing frontal position.

While you may infer *frontal intensity* (weak, moderate, or strong) from this chart, you would need to compare this chart to previous charts to infer *frontal type* (cold, warm, occluded) and *frontal character* (undergoing frontogenesis, undergoing frontolysis, or having no change).

Surface-Weather Prognostic Charts

Surface prognostic charts, or forecasts of the surface pressure, surface wind, and frontal depiction, are produced every 12 hours, beginning at 0000Z. Surface-pressure prognoses are available out to 120 hours (5 days). Figure 4-2-4 shows a typical *surface-wind* and *surface-pressure* prognosis. Winds and pressure are depicted the same as on the analysis charts. *Frontal depiction* prognosis charts are produced to match the area and map projection of the surface prognosis charts.

This polar stereographic map projection example (fig. 4-2-4) is typical of most of the charts produced for the mid-latitude users. The winds are plotted on a grid with spacing between grid points of about 5 degrees latitude at 15 °N, or about 300 nmi. As you look farther north, you

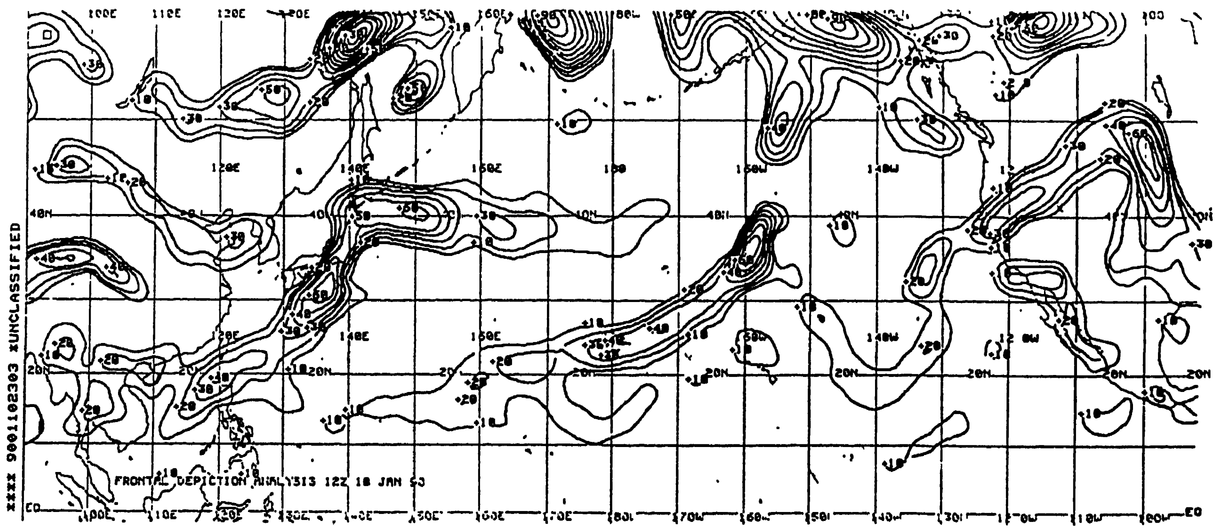


Figure 4-2-3.—Frontal depiction analysis.

may notice that the same grid spacing is equivalent to about 7 degrees latitude at 50 °N, or about 420 nmi. This means that at 15 °N the wind plot represents an average wind for a 90,000-square-mile area, while at 50 °N the wind plot represents an average wind for a 176,400-square-mile area, or about one-half the resolution. You must keep that in mind when using these charts to make your forecast. Sometimes it is preferable to use a geostrophic wind scale and isobar spacing to determine forecast winds, instead of the winds plotted on the chart.

Learning Objective: Interpret FNOC constant-pressure and freezing-level charts.

UPPER-AIR CHARTS

The *upper-air* analyses and prognosis charts are all very similar. Analyses are routinely produced for the 850-, 700-, 500-, 400-, and

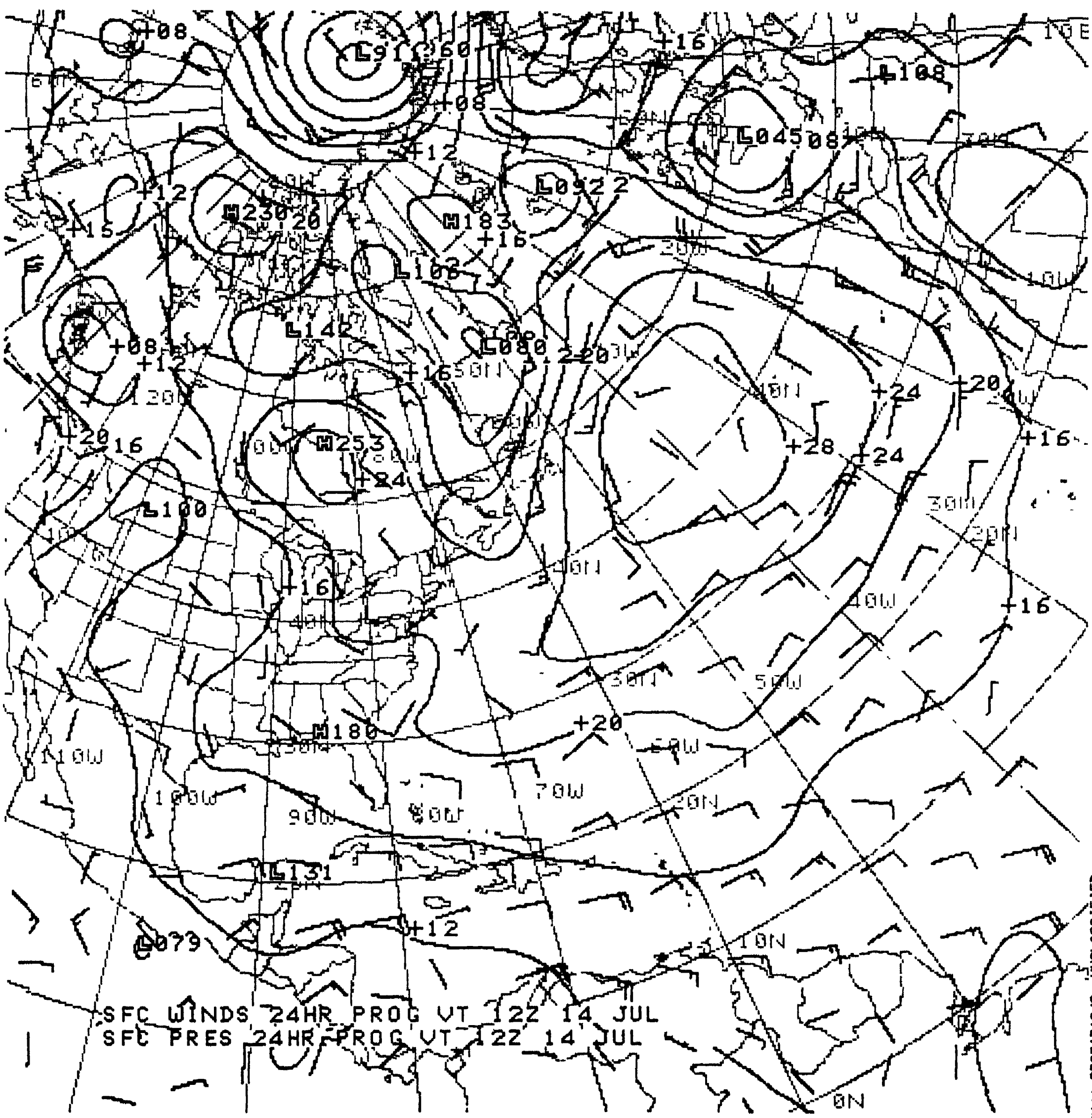


Figure 4-2-4.—Surface-wind and surface-pressure prognosis.

300-, and 200-millibar levels. **Figure 4-2-5** shows an 850-millibar analysis on a polar stereographic map projection as used in the mid-latitudes. Figure 4-2-6 shows a 500-millibar, 48-hour prognosis. Except for the chart identification and contour labeling, these charts are very similar. The winds, temperature, and height prognosis data fields are usually combined on a single chart for each of the various constant-pressure surfaces. Winds are represented with standard plots; height contours (isoheights), by solid lines; and temperature (isotherms), by dashed lines. All charts use a 5 °C isotherm interval, with the temperatures labeled in degrees Celsius. The 850-millibar chart uses a 30-meter isoheight interval; the 700- and 500-millibar charts use a 60-meter isoheight interval; and the 400-, 300-, and 200-millibar charts use a 120-meter

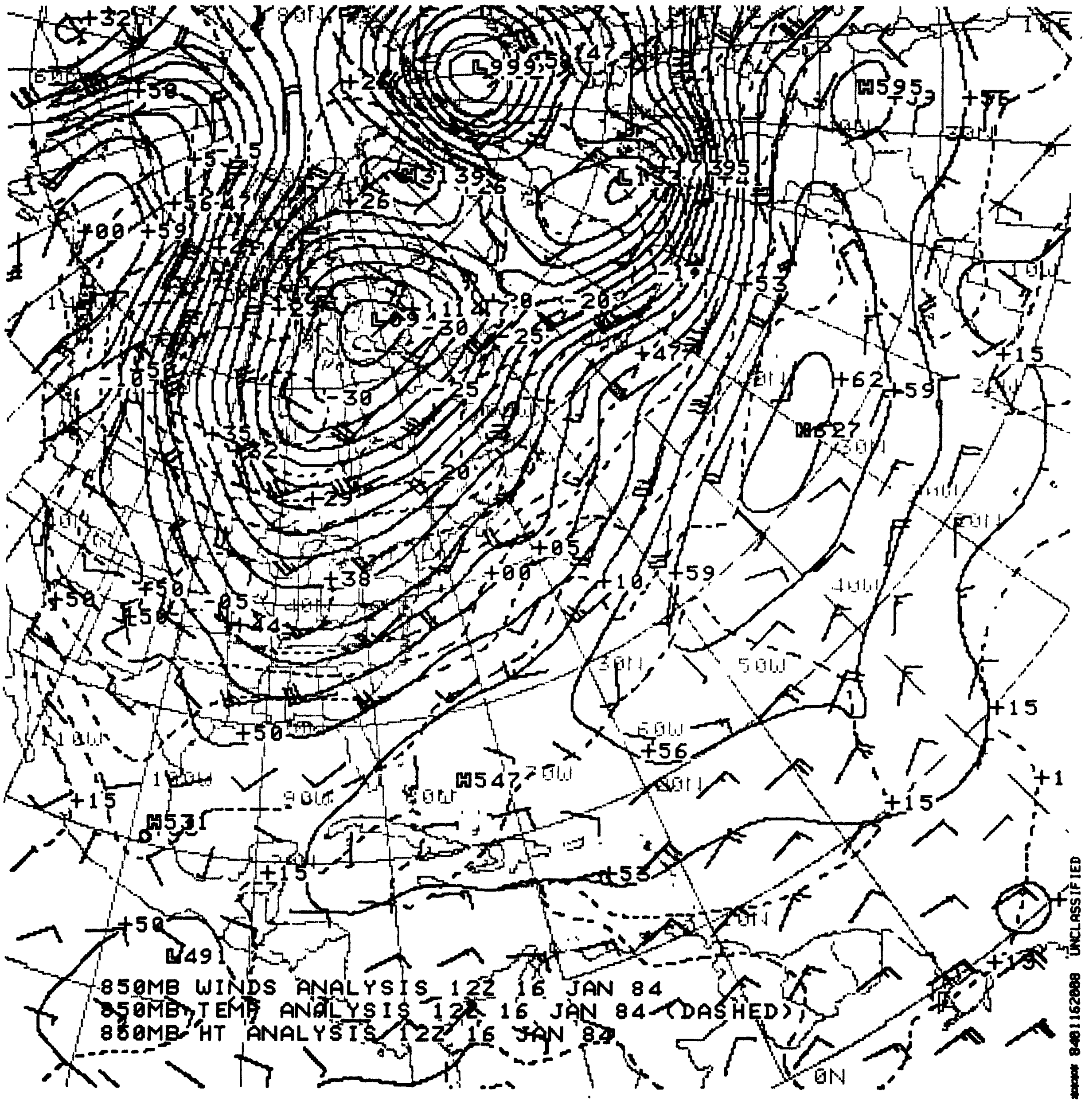


Figure 4-2-5.—850-millibar analysis.

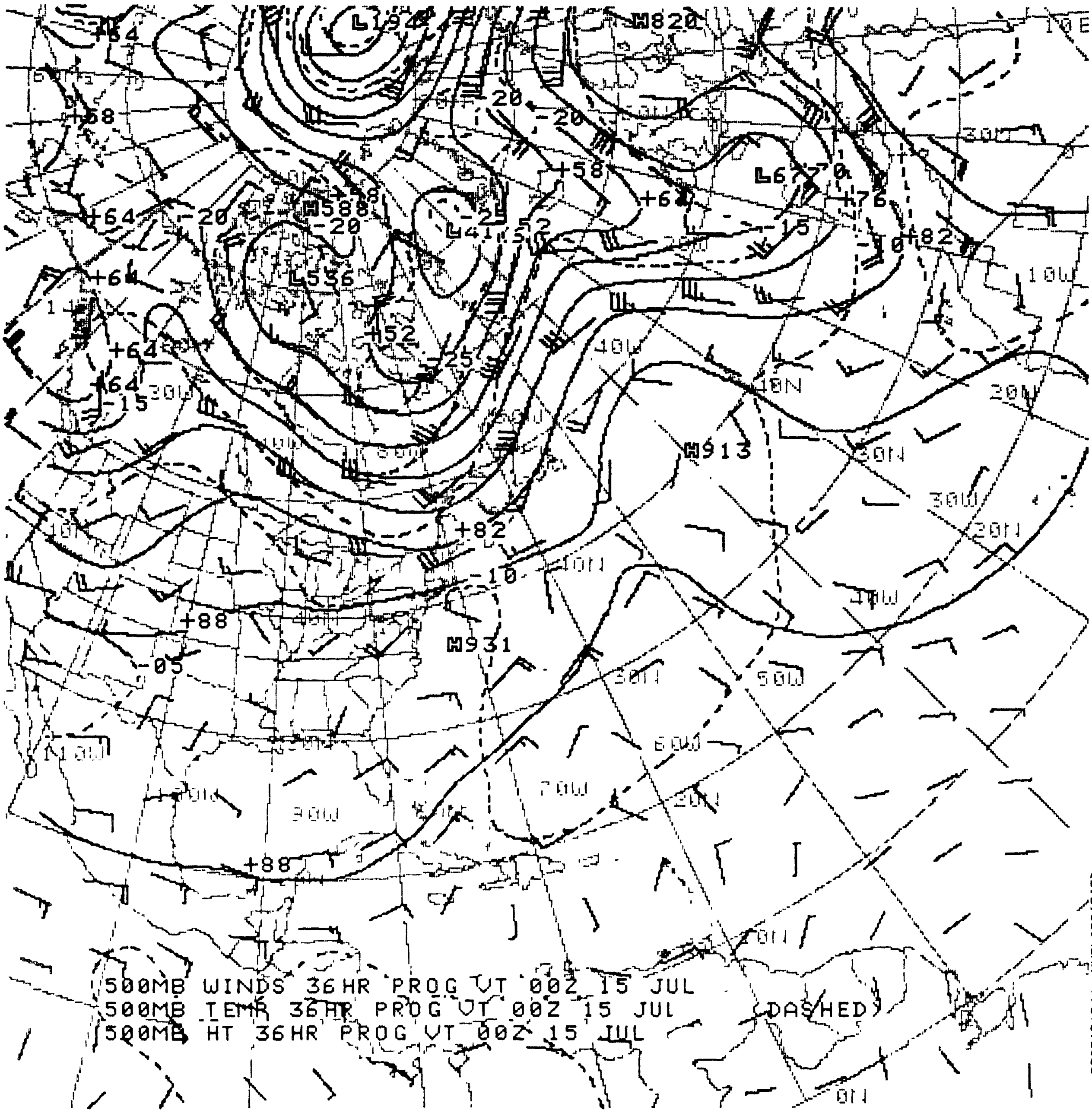


Figure 4-2-6.—500-millibar prognosis.

isoheight interval. While the 500-millibar level is routinely available in 12-hour increments out to 120 hours, and the other levels are routinely available in 12-hour increments out to 72 hours, the charts transmitted on the Fleet Facsimile broadcasts are usually limited to the 24- and 48-hour forecasts. Generally, products distributed to the fleet are tailored by the NOC centers.

FREEZING-LEVEL CHARTS

The FNOC computers calculate the freezing level during the analysis and during the forecast model runs. *Freezing-level* analyses and

prognostic data fields are produced routinely twice a day out to 72 hours. Figure 4-2-7 shows a typical freezing-level prognostic chart. Solid lines depict only the lowest freezing level. The contour labeled 00 indicates the freezing level at the surface. Additional contours are depicted every 500 meters, and labeled in hundreds of meters. Since flight weather briefs require freezing levels in feet, the user must convert the heights in meters to feet.

Always be alert for signs of multiple freezing levels. The most dangerous aircraft icing, severe clear ice, can occur when liquid precipitation falls into a layer of freezing air. Precipitation in areas with multiple freezing levels may indicate severe clear icing. This chart will not indicate those situations properly.

Besides producing meteorological analyses and forecast charts, FNOC also produces many oceanographic charts. Several of these oceanographic charts are discussed in the next section.

Learning Objective: Interpret various oceanographic charts produced by FNOC.

OCEANOGRAPHIC CHARTS

The oceanographic charts produced by the computers at FNOC provide analyses and forecasts of conditions that directly effect daily operations in the Navy's antisubmarine warfare effort, as well as routine ship operations. Computer interface with the climatological data base and with data files of current and near-current oceanographic observations allows development of a

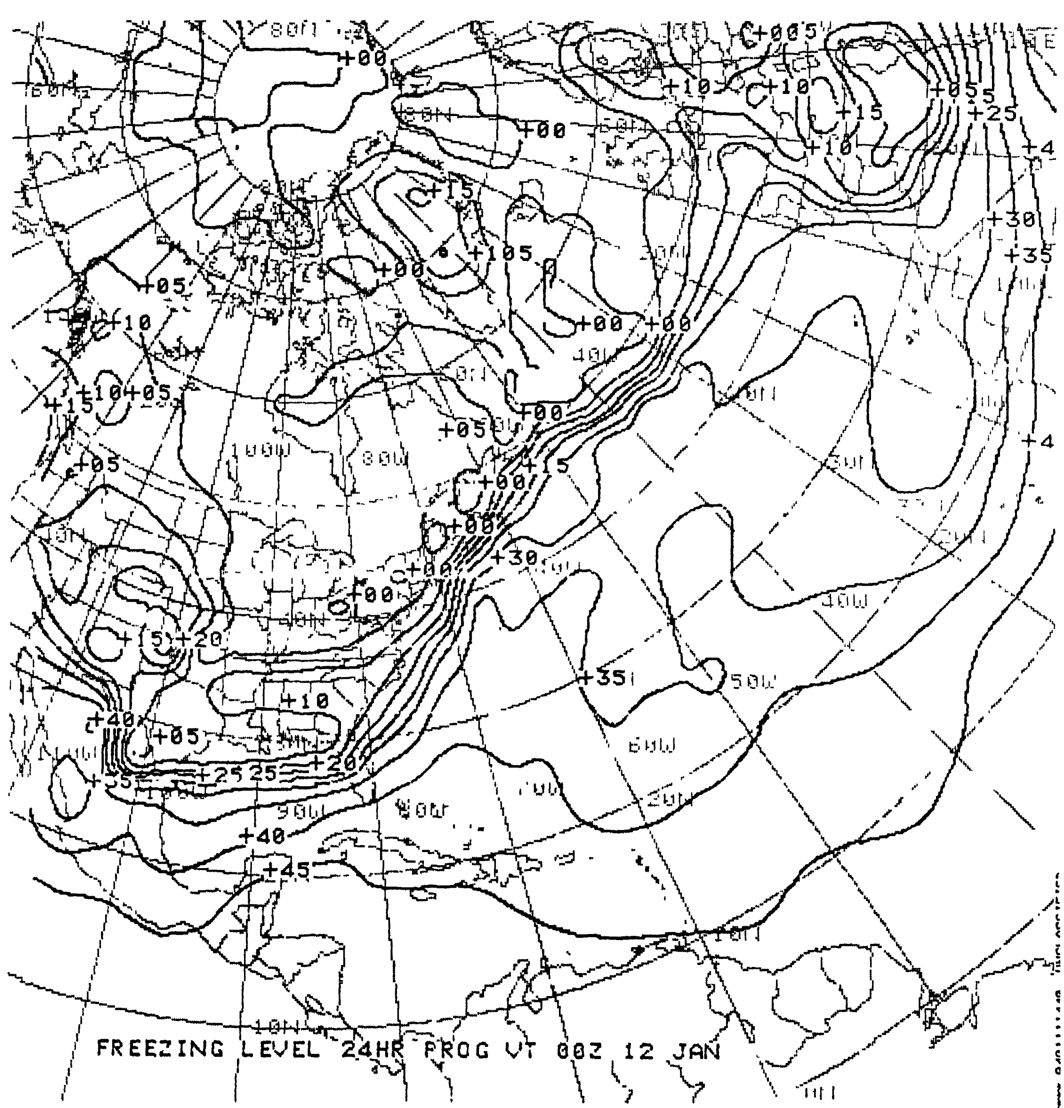


Figure 4-2-7.—Freezing-level prognosis.

much more accurate depiction of oceanographic features than is possible by a single oceanographic analyst/forecaster. However, over-smoothing of the data fields on the large-scale charts routinely transmitted via facsimile may mask significant details necessary for certain applications. Products transmitted over the unencrypted facsimile broadcast may be intentionally over-smoothed so as not to yield details of significant oceanographic features to non-NATO naval forces who routinely intercept and use the data from the broadcast. For applications requiring greater accuracy and detail, the Automated Product Request (APR) system should be used to receive oceanographic products via encrypted channels.

In this section we will discuss the Sea Surface Temperature analysis, the Sea Surface Temperature Anomaly analysis, the Significant Wave Height analysis and prognosis, the Mixed Layer Depth analysis and prognosis, and the Sonic Layer Depth analysis charts. All of these products are routinely available on Mercator projections or as polar stereographic-map projections in a wide range of map scales. The examples provided in the text are generally the larger scale map projections.

Sea Surface Temperature Analysis

The *sea surface temperature* analysis shown in figure 4-2-8 is typical of the low-resolution

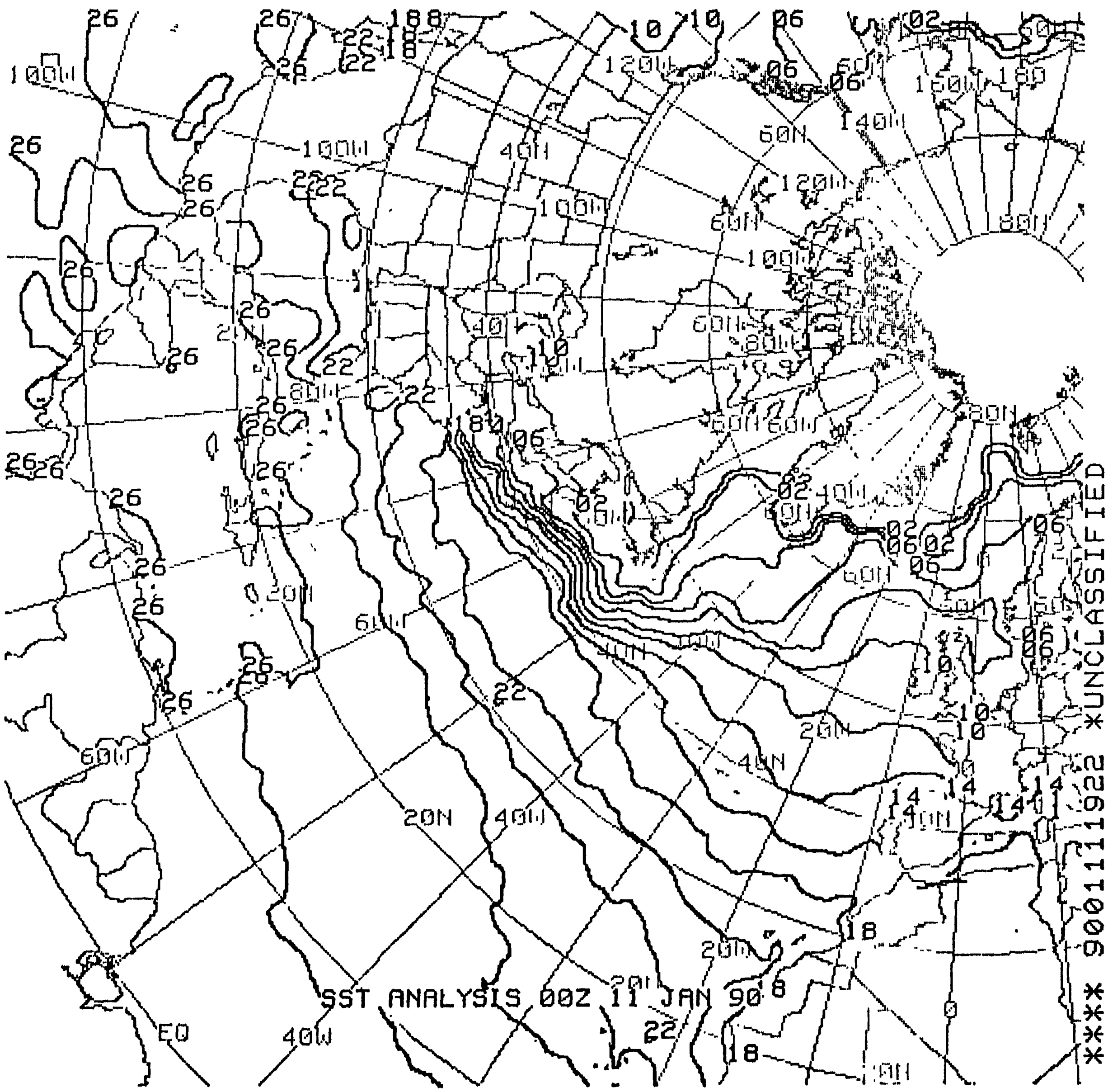


Figure 4-2-8.—Sea surface temperature analysis.

product transmitted via the facsimile broadcast. Solid lines are used to depict sea surface temperature isotherms every 4 °C. A similar, medium-resolution chart is also transmitted that uses a 2 °C isotherm interval. Very small scale, high-resolution charts are available on the NEDS that which use a 1 °C interval or less.

Sea Surface Temperature Anomaly Analysis

The *sea surface temperature anomaly* chart depicts areas that are warmer or cooler than the climatic normal for the month. Areas enclosed with an isotherm that show a negative temperature are colder than normal. The example shown in

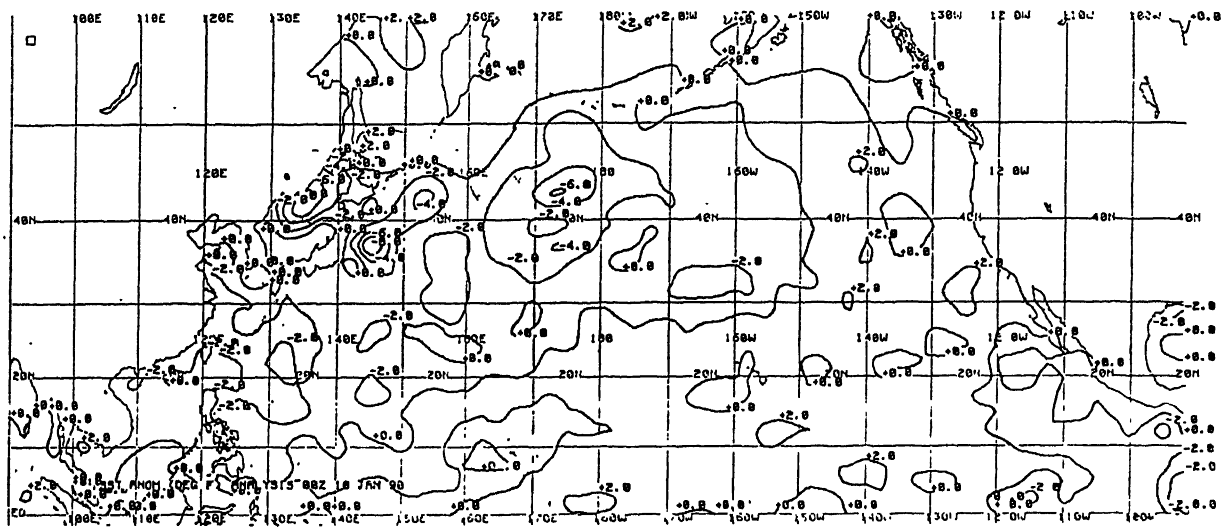


Figure 4-2-9.—Sea surface temperature anomaly analysis.

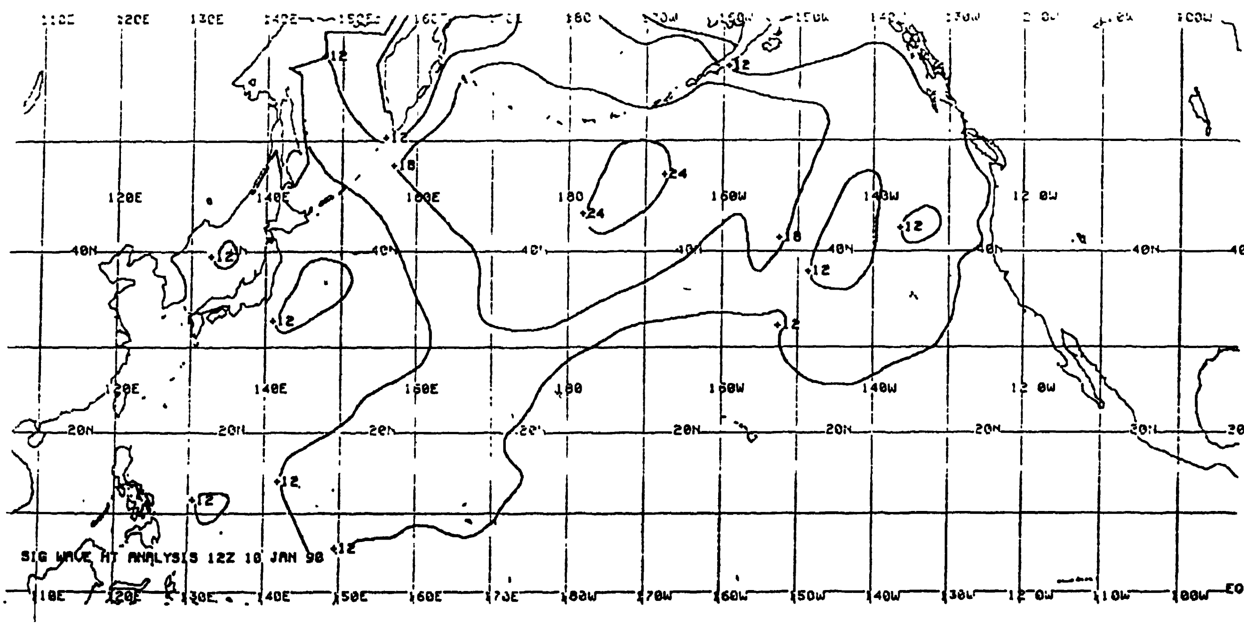


Figure 4-2-10.—Significant wave height (hemispheric) analysis.

figure 4-2-9 is a Mercator hemispheric projection that uses a 2 °C contour interval. Regional analyses are also available that use a 1 °C isotherm interval.

Significant Wave Height Analysis and Prognosis

The *significant wave height* (SIG WAVE HT) analysis and prognosis charts are very useful for daily shipboard sea state forecasting, heavy weather avoidance, and Optimum Track Ship Routing. Figure 4-2-10 shows a typical low-resolution hemispheric analysis. Figure 4-2-11 shows a typical regional prognosis. The hemispheric analysis uses a 6-foot wave height contour interval starting at 12 feet; the regional analyses and forecasts use a 3-foot contour interval beginning at 3 feet.

The significant wave height charts do not specifically show wind wave heights or swell wave heights. It shows computer calculations of the significant (highest one-third) of the sea waves (waves produced by the local winds) based on the fetch and duration from the analyzed and forecast surface wind fields. It will not indicate the swell waves, which may at times be higher than the sea waves. It also does not indicate a prevailing wave

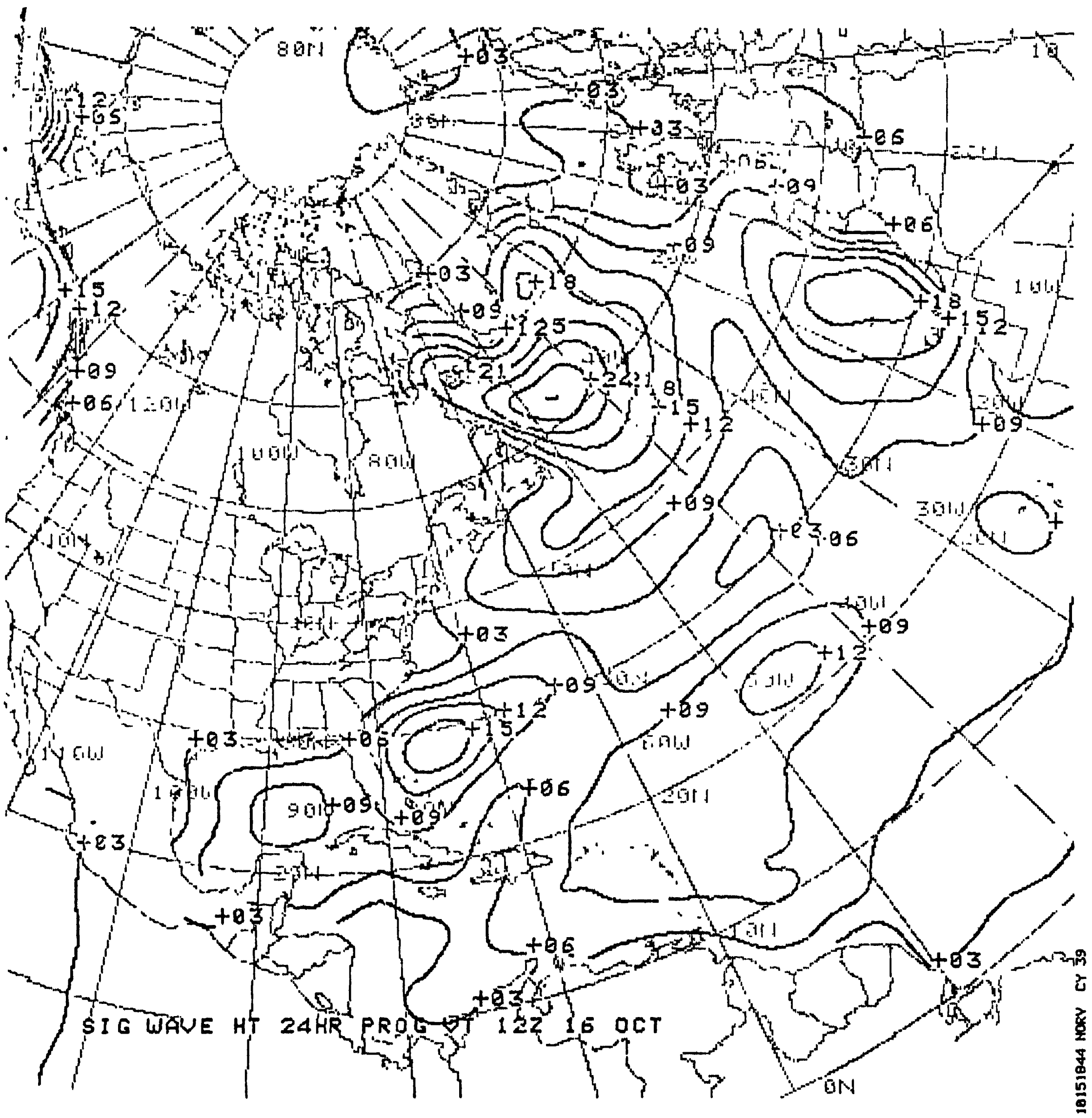


Figure 4-2-11.—Significant wave height (regional) prognosis.

direction, although this may be inferred by comparing the SIG WAVE HT charts to the corresponding surface wind charts; the primary wave direction should be the same as the direction the wind is blowing towards. Remember, though, that wind directions are reported as the direction the wind is coming from; wave directions are reported as the direction the waves are moving to.

Most of the Fleet Facsimile Broadcasts also include charts, manually produced at the Oceanography Centers, that include swell wave heights. These are the *Combined Sea Height* charts. The combined sea height is actually the highest wave height at the points where the significant sea waves merge with the swell wave. Where these waves meet, a higher wave is formed than either the highest sea-wave height or the highest swell-wave height alone. The combined sea height, C, is calculated from both the sea-wave height (either the reported significant sea-wave height or the computer-calculated significant sea-wave height) and the swell wave height by the formula

$$C = \sqrt{(\text{seas})^2 + (\text{swell})^2}\,.$$

The combined sea height charts also indicate the prevailing wave direction with an arrow.

It is important that you know the differences between the combined sea height chart and the significant wave height chart. They are not intended to show the same parameters and should rarely look exactly alike. Comparison of both types of charts for corresponding times will give you a good overall picture of the swell wave, the sea waves, and the general sea state.

Mixed Layer Depth Charts

The *mixed layer depth* (MLD) analysis chart shown in figure 4-2-12 depicts the depth of the mixed layer, in meters. Contours are drawn on the hemispheric chart at 10, 20, 30, 45, 60, 80, 100, 140, 180, 230, and 280 meters. The deeper the mixed layer, the larger the contour interval.

The MLD is the bottom of the uppermost layer of the ocean, the Mixed Layer, which, because of mixing by waves and currents, is usually fairly isothermal or shows only a slightly negative temperature gradient with depth. The MLD is also considered the top of the second ocean layer, the Main Thermocline, where the temperature decreases rapidly with depth. Because of the sharp decrease in the temperature gradient with depth at the MLD, the MLD usually, but not always, is the point of maximum sound velocity in the upper 1,500 feet of the sea. In the cases where the MLD is the point of maximum sound velocity, it is also known as the Sonic Layer Depth (SLD).

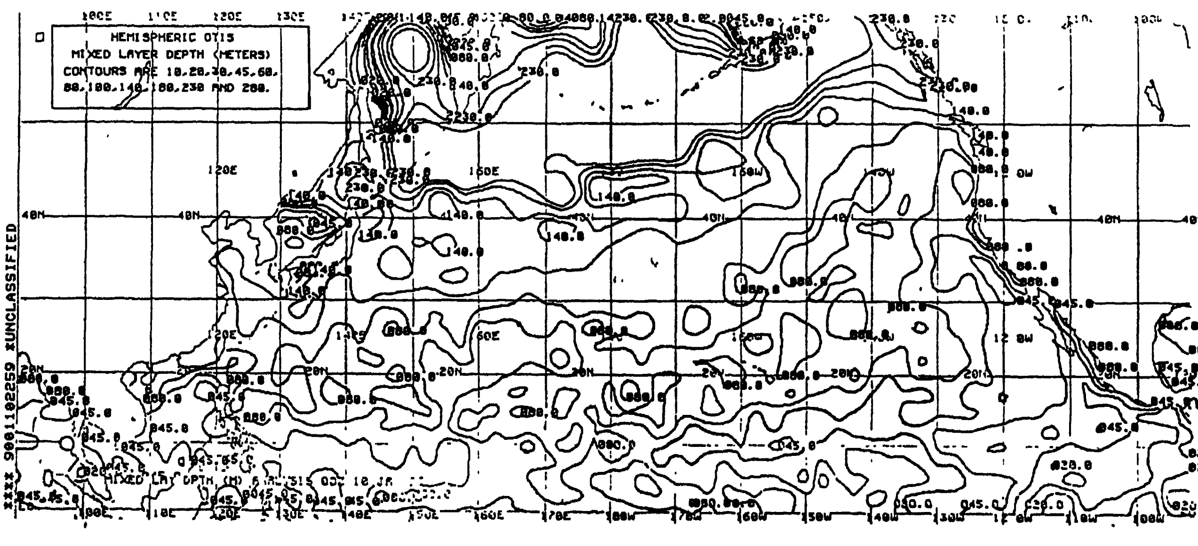


Figure 4-2-12.—MLD analysis.

Prognostic charts of the forecast change in the MLD are available in addition to the analyses. Figure 4-2-13 shows a full hemisphere (Northern) polar stereographic projection of the 24-hour forecast changes in the MLD, which are due to increasing or decreasing wave heights. The contours are in meters, with a 4-meter interval. Negative values indicate an increasing MLD (the MLD becomes deeper); positive values indicate a decreasing MLD.

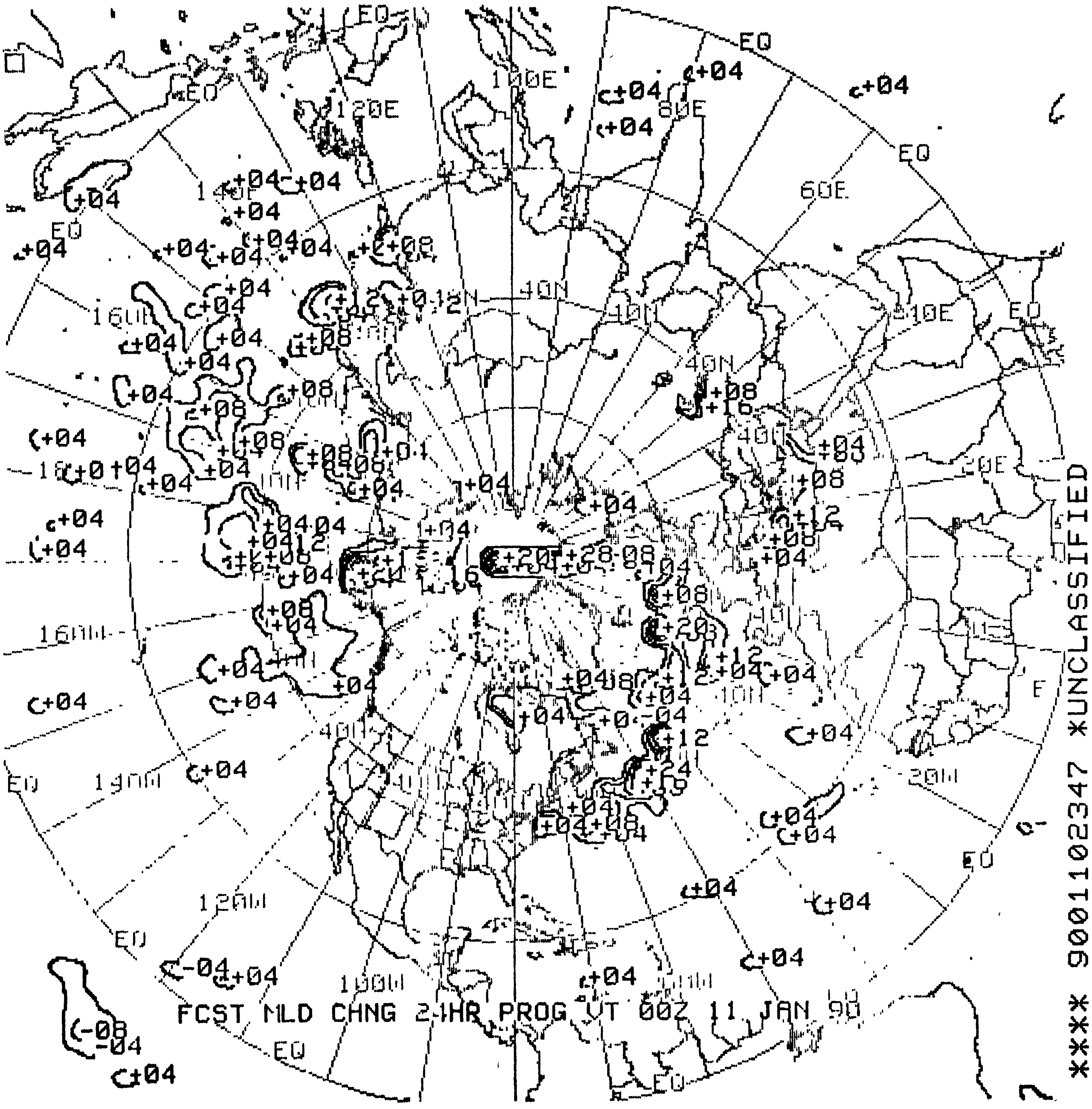


Figure 4-2-13.—MLD change prognosis.

Sonic Layer Depth Analysis

The Sonic Layer Depth (SLD) analysis chart as shown in figure 4-2-14 on a Mercator map projection uses shading instead of contours to indicate the depth of the maximum speed of sound near the surface. The different types of shading indicate ranges of the SLD in feet: no horizontal shading lines (clear) indicate an SLD between the surface and 50 feet; widely spaced horizontal lines (light) indicate SLD depths between 50 and 100 feet; closely spaced lines (medium) indicate depths from 100 to 350 feet; and very closely spaced lines, forming the darkest (heavy) shading, indicate depths deeper than 350 feet. Since the SLD may coincide with the MLD as deep as 1,500 feet, the MLD analysis, which contours down to 280 meters (about 900 feet), may be more useful for many applications. Reanalysis of this chart by drawing in the 50-, 100-, and 350-foot contours makes it a better briefing tool and equates roughly to the 15-, 30-, and 100-meter contours on the MLD analysis. FNOC also produces this chart with the contours in feet vice meters.

You have seen a few of the charts that are available for oceanographic applications on many different map projections and scales. The basic presentation of features on these charts are all very similar, regardless of the resolution used. Just about every data field that is presented in chart form is also available as a message of gridded point values, which may be transmitted over various communications circuits to suit your requirements.

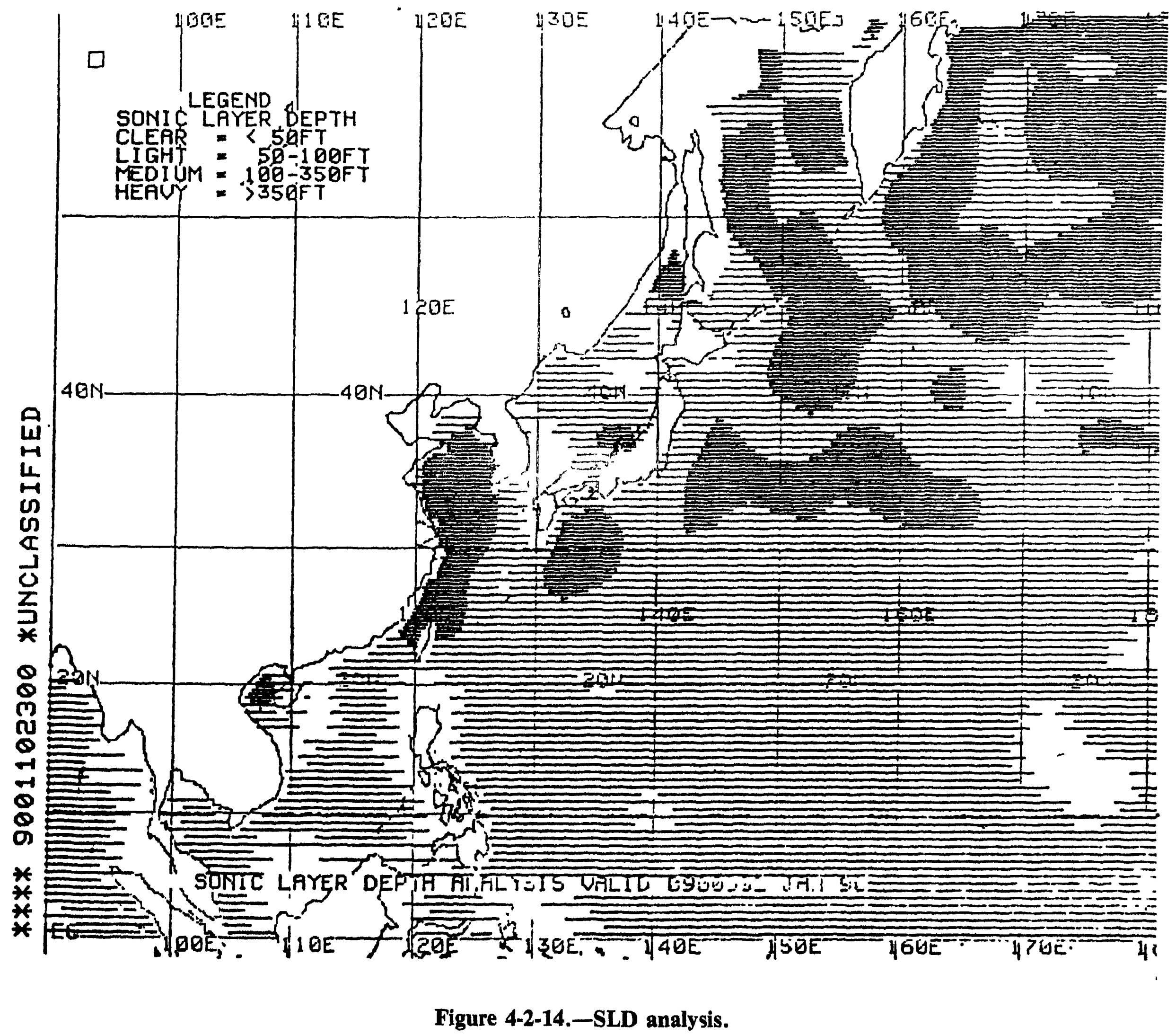


Figure 4-2-14.—SLD analysis.

Learning Objective: Identify the sources to obtain information on the request procedures for message format gridded data fields.

MESSAGE PRODUCTS

AWSP 105-52, volume III, *Weather Message Catalog*, lists MANOP headers for many predesignated FNOC meteorological and oceanographic products in gridded format, ranging from surface winds and upper-level winds to highly detailed sea-wave spectrum predictions for specified points. In addition, *Automated Product Request (APR) User's Manual*, FLENUMOCEANCENINST 3140.3, describes procedures for requesting various data fields and specialized meteorological and oceanographic products. A new instruction, *General Acoustic Conditions Depiction System User's Guide*, FLENUMOCEANCENINST 3145.3, describes various acoustic-conditions graphic products, as well as alphanumeric gridded products available from FNOC via NEDS, NODDS, and AUTODIN message.

Learning Objectives: Identify the Acoustic Range Prediction products available from FNOC; identify the manual that describes the request procedures for the products; and identify the manual that describes the product format and interpretation guide.

ACOUSTIC RANGE PREDICTION PRODUCTS

FNOC provides acoustic range prediction products in support of active and passive sonar systems. The Acoustic Sensor Range Prediction (ASRAP) and the Predesignated High Interest Tactical Area (PHITAR) products were developed to support passive systems. Active systems are supported by the Active ASRAP and the Ship/Helicopter Acoustic Range Prediction System (SHARPS) products. Although briefly described in this section, these products and their applications are thoroughly described in the classified NAVOCEANCOMINST C3140.22, *The NAVOCEANCOM Environmental Tactical Support Products Manual (U).* Request procedures are found in the *Automated Product Request (APR) User's Manual.*

ASRAP Products

ASRAP is an omni-directional product that provides the tactician with expected acoustic ranges for user-specified or default-source depth/receiver, depth/frequency combinations. This product supports all aircraft and surface ship passive sonar systems and is available in four modes:

- ASRAPC—Frequency Mode; the various source depths and receiver depths are depicted for each frequency.

- ASRAPR—Receiver Mode; the various frequencies and source depths are depicted for each receiver depth.

- ASRAPS—Source Mode; the various frequencies and receiver depths are depicted for each source depth.

- ASRAPV—VLAD Mode; for use with the Vertical Line Array DIFAR (VLAD) sonobouy.

ASRAP one-way propagation-loss information is also applicable to shipboard passive sonar systems. This product is primarily used by the VP squadrons.

Active ASRAP Products

The Active ASRAP product was developed to support active airborne sonar systems. This product supports the SSQ-47, SSQ-50, and SSQ-62 active sonobouys. Range predictions are provided for different system modes and source/receiver depth combinations which may be user-specified. The product is used by both VP and carrier based ASW squadrons, as well as by surface combatants.

SHARPS Products

SHARPS was developed to support shipboard and helicopter active sonar systems, but now includes support for the passive mode as well. This product may be fully tailored using specified sonar parameters for individual ships. The product

displays a 50-percent probability of detection range as a function of sonar mode, ship's speed, and transmission path (direct, convergence zone, and bottom bounce). Estimated passive and active counter detection ranges are also provided.

PHITAR Products

PHITAR primarily provides propagation-loss data to submarines in a communications efficient form, although it is also used by air and surface ASW squadrons. It is available in three modes:

- PHITAR—Receiver Mode; the various frequencies and source depths are depicted for each receiver depth.

- PHITARF—Frequency mode; the various source depths and receiver depths are depicted for each frequency.

- PHITARV—VLAD Mode; used with the VLAD sonobouy.

PHITAR propagation-loss data is used by the requestor to plot propagation-loss (proploss) curves and thereby determine expected passive acoustic ranges for the sonar systems of interest.

Because of the sensitivity of the information contained in the actual Acoustic Range Prediction products, we cannot present meaningful examples of each product or provide a breakdown of the message format. To properly interpret these products, you should consult *NAVOCEANCOM Environmental Tactical Support Products Manual.*

SUMMARY

In this lesson we have discussed a few of the most widely used products available from the U.S. Navy's Fleet Numerical Oceanography Center. Many specialized computer produced products are available for your use that we have not even mentioned. You should take the time some quiet mid-watch to look through *APR User's Manual*, *General Acoustic Conditions Depiction System Users Guide*, and if you have the required clearance, through the *NAVOCEANCOM Environmental Tactical Support Products Manual* to familiarize yourself with some of the other computer-produced products available.

UNIT 4—LESSON 3

NATIONAL WEATHER SERVICE CHARTS AND PRODUCTS

OVERVIEW	OUTLINE
Identify the types of National Weather Service products and the routine methods used to distribute these products to Naval Oceanography Command and Fleet Aerographer's Mates.	General types of National Weather Service products Availability of NWS products to Naval Oceanography Command units Availability of NWS products to Fleet Aerographer's Mates Informational sources about NWS products, availability, and schedules
Identify the major numerical prediction models used by the National Weather Service.	Numerical prediction models used by the National Weather Service
Identify parameters on the most frequently used National Weather Service facsimile charts.	Parameters on NWS facsimile charts Surface analysis Weather depiction analysis Radar Summary analysis Upper-air analysis Composite analysis 12-hour upper wind forecast 12- to 48-hour Boundary Layer wind forecast 12- to 48-hour surface weather forecast series NGM 12- to 48-hour forecast series MOS probability forecast Mid-range surface forecast Mid-range temperature forecast
Interpret commonly used National Weather Service bulletins.	Interpretation of frequently used coded bulletins

NATIONAL WEATHER SERVICE CHARTS AND PRODUCTS

The National Weather Service (NWS), headquartered in Suitland, Maryland, operates as a branch of the National Oceanic and Atmospheric Administration (NOAA), under the U.S. Department of Commerce.

The National Weather Service computers at the National Meteorological Center (NMC) in

Suitland are the focal point for meteorological data collection in the United States. As a member of the World Meterological Organization (WMO), NWS also shares selected data and products with all other member nations in the WMO via the WMO data collection computer system based in Geneva, Switzerland.

Learning Objective: Identify the types of National Weather Service products and the routine methods used to distribute these products to Naval Oceanography Command units and Fleet Aerographer's Mates.

GENERAL TYPES OF NATIONAL WEATHER SERVICE PRODUCTS

Most of the observational and prognostic data routinely received from foreign countries by NWS is in the form of digital messages, although some digital charts are received. The National Weather Service computers at the National Meteorological Center (NMC) automatically receive and process all data received from North America and the remainder of the world. Selected raw observational data is routinely used in various numerical prediction models to produce both graphic charts and numerical bulletins.

NWS also receives copious amounts of digital satellite imagery and computer-derived digital data from another branch of NOAA—the National Environmental Satellite, Data, and Information Service (NESDIS).

A large portion of the data received at NMC and the products produced by NMC are available to the Department of Defense. While most of this data is provided to DOD as digital data fields (intended to load a computer with semi-processed data or computer-derived data), a good portion is provided to DOD users as either facsimile charts or electronically transmitted bulletins. In this lesson we will discuss only a few of the thousands of charts and bulletins provided by NWS.

AVAILABILITY OF NWS PRODUCTS TO NAVAL OCEANOGRAPHY COMMAND UNITS

How do you, as an Aerographer, receive these facsimile charts and electronic bulletins? Most of the NWS products you will use will come from NMC through the Department of Defense/ Defense Communications System (DOD/DCS) Global Weather Communications System's (GWCS) Automated Weather Network (AWN). The hub of the AWN is the Automated Digital Weather Switch (ADWS) at Carswell AFB. Carswell is connected with nearly every DOD weather facility in the continental United States. NMC data and bulletins are sent directly from ADWS to your COMEDS printer or computer terminal. Additional data is sent to Fleet Numerical Oceanography Center (FNOC) Monterey for processing and further distribution via the Naval Environmental Data System (NEDS) to Naval Oceanography Command (NOC) Centers, Facilities, or Detachments. Rota, Hawaii, and Guam all may receive NWS data and bulletins via the Naval Environmental Data Network (NEDN).

NWS facsimile charts are retransmitted on the Air Force Digital Graphics System (AFDIGS), a second major component of the DOD/DCS GWCS. NOC Centers may receive this data via land-line circuits or satellite and retransmit selected data via their facsimile broadcasts to the fleet.

NWS operates the direct Satellite Facsimile (SATFAX) broadcast which is currently used by most U.S. Marine Corps weather detachments and many stateside NOC Detachments. NWS also operates the National Facsimile (NAFAX) circuits which are available at many CONUS NOC Units. The NAFAX circuits are being phased out and replaced by SATFAX. Additionally, NWS maintains localized and specialized facsimile broadcasts, such as the Inter-Alaska Facsimile (AKFAX) circuit, the Suitland-Honolulu circuit, the Tropical Analysis (TROPAN) circuit, and a special circuit for Puerto Rico and the Virgin Islands. These are available to DOD users. All of these circuits contain regional and global charts produced by NWS.

AVAILABILITY OF NWS PRODUCTS TO FLEET AEROGRAPHER'S MATES

The NOC fleet facsimile broadcasts are composed mostly of FNOC-produced charts. Supplemental charts are received directly from NMC via the NWS SATFAX broadcast, the NWS Digital Facsimile (DIFAX) broadcast, or received indirectly from NMC on the AFDIGS broadcast from the Air Force Global Weather Center (AFGWC). The Navy's fleet meteorological data

broadcast, part of the Fleet Multi-channel Satellite Broadcast, originates at Carswell AFB, with data received from NWS. This data is supplemented with data inserted by the NOC Centers. While most of the data transmitted from outside the United States is received at the NOC Centers on the NEDN, the majority of the data, including the overseas data, is provided by NWS. It may be interesting to remember the next time you receive some local weather data aboard ship off the coast of Malaysia, that the data actually traveled around the world, from Malaysia to Switzerland; to Suitland, Maryland; to Carswell AFB, Texas; to Hawaii; to Guam; and finally to your ship.

Although the NWS regional HF teletype broadcasts were discontinued several years ago, the current operational and planned AFDIGS HF broadcasts should provide a valuable facsimile and teletype data source for our use. AFDIGS actually has four digital graphics weather circuits: CONDIGS, for the continental United States; PACDIGS, for the Pacific; HALDIGS, for Central America; and EURDIGS, for Europe. Until recently, the only way to receive any of the AFDIGS products was to be connected to a dedicated land-line/satellite circuit. Current plans for the USAF High Frequency Regional Broadcast (HFRB) System include multiple HF radio broadcast sites for all of the AFDIGS broadcasts. AWS and NWS facsimile charts are transmitted on the upper sideband, with AWS, NWS, and foreign data and bulletins being transmitted via radioteletype on the lower sideband of each frequency. As of late 1989, the currently operational sites are Elmendorf AFB, Alaska and Elkhorn, Nebraska. Six additional sites will be brought on line by the end of 1991: Anderson AFB, Guam, for the western and central Pacific; Clark AFB, Republic of the Philippines, for the Far East and the Indian Ocean; Croton AB, England, for Europe, the eastern North Atlantic and Barents Sea; Incirlick AB, Turkey, for Southern Europe, the Mediterranean, and the Middle East; Homestead AFB, Florida, for the Caribbean, Central America, and southern United States; and one additional site for the South Atlantic. Information on frequencies and data content is contained in AWSR 55-9. Requests for frequencies and special support should be addressed to COMNAVOCEANCOM.

Additionally, limited NWS charts are available on the satellite Weather Facsimile (WEFAX) broadcasts from the geostationary Earth-orbiting satellites (GOES) operated by the National Environmental Satellite, Data, and Information Service (NESDIS). Several different NWS charts are routinely retransmitted by the Soviets, the British, the Germans, and the Italians on their meteorological HF broadcasts.

INFORMATIONAL SOURCES ABOUT NWS PRODUCTS, AVAILABILITY, AND SCHEDULES

Now that you know that a multitude of NWS products are available for your use, how do you find out the purpose of all these charts and bulletins?

National Weather Service Forecasting Handbook No. 1, Facsimile Products, describes many of the different NWS analysis and prognosis charts in detail and gives descriptions of the numerical prediction models used to produce these charts. This book should be available in every U.S. weather office, including the Navy and Marine Corps weather offices.

The NWS *Technical Procedure Bulletins* (TPBs) series describes, in detail, changes implemented in the various analysis and prognosis models, formats for various bulletins, a breakdown of the coding used in many bulletins, and techniques for making best use of information in the bulletins. SATFAX and NAFAX schedules are also issued as TPBs. TPBs should be read by every meteorological technician and forecaster. Unfortunately, when TPBs are received, too often they are "pigeon-holed" somewhere or discarded instead of being held as ready reference material.

The best overall listing of facsimile product availability is contained in AWSP 105-52, Volume I, *Facsimile Products Guide*, on microfiche. This lists both NWS and AFGWC facsimile products, and provides information on MANOP headings (if they have been assigned), area coverage, and on what data is provided.

ASWP 105-52, Volume III, *Weather Message Catalog*, provides similar information on all standard and special-use bulletins produced by the NWS, AFGWC, and Naval Oceanography Command units, as well as bulletins available from foreign countries. MANOP headings, area coverage, coding, and other specifics of each bulletin are provided if available. This also is available on microfiche and is updated quarterly. (Volume II in this series is the *Weather Station Index* (worldwide coverage) and does not apply to this lesson.)

Schedules for the four AFDIGS circuits are issued as a message on a monthly basis. Any DOD user of AFDIGS may be placed on distribution for the appropriate circuit schedule.

WEFAX schedules and frequencies are issued by NWS to selected users. The Naval Polar Oceanography Center (NPOC) Suitland re-issues these schedules and frequencies in their *Satellite Information Notes* to naval units.

Frequencies for the foreign weather broadcasts, both facsimile and radioteletype (RATT), which may contain selected NWS products, are contained in *Selected Worldwide Marine Weather Broadcasts*, DMA WWMARWEATHRBC, and in AWSR (Air Weather Service Regulation) 100-1, *Global Weather Intercepts*. You will find the AWS source a much better reference when researching foreign frequencies for shipboard and mobile team use. Most domestic and foreign meteorological facsimile broadcasts transmit, at some time during the day, a detailed transmission schedule.

Information on the breakdown of many of the codes used in NWS and foreign weather bulletins and on some facsimile charts is contained in NAVAIR 50-1P-11, *International Meteorological Codes*, 1984 edition (one of your required publications).

Learning Objective: Identify the major numerical prediction models used by the National Weather Service.

NUMERICAL PREDICTION MODELS USED BY NWS

NWS currently uses several different numerical prediction models for different applications. We will not go into any great detail at this level, but in *AG1&C* you will learn the strengths and weaknesses of each model.

Limited Fine Mesh Model II

The Limited Fine Mesh Model II (LFMII) is still used for many 48-hour forecasts. (These are called short-range forecasts.) Basically, it forecasts seven layers of the atmosphere: a planetary-boundary layer 50 millibars (about 1,500 feet) above the surface; three evenly spaced layers in the troposphere, including a layer at the tropopause level; and three evenly spaced layers in the stratosphere, with the top layer at 50-millibars. See figure 4-3-1 for a diagram of the layer structure of the LFMII model. Forecasts at each layer are done on a grid with grid points about 116 kilometers apart at 45° latitude.

Nested Grid Model

Since late 1985 the Nested Grid Model (NGM) has also been run for the North American continent in addition to the LFM. The NGM is part of the NWS Regional Area Forecast System (RAFS) plan to improve the accuracy of numerical forecasts for the United States. It uses 16 layers in its calculations (more than twice as many as the LFM) and a series of 3 nested grids. The model makes calculations for the entire Northern Hemisphere on its coarsest (most widely spaced grid points) grid, grid A. Grid B is a finer, polar-stereographic grid; it generally covers North America, much of the Pacific, some of the Atlantic, and the polar region. Grid C is the smallest and finest-mesh grid; it covers the eastern Pacific and North America. The resolution of grid C is 84 kilometers at 45°, much finer than the LFMII. The larger-amplitude atmospheric waves are calculated on the course grid, A. When these features enter the area covered by the finer grids, information is exchanged and calculations proceed on all three grids, with constant error checking. The boundary layer is only 35 millibars above the surface, or about 986 feet AGL. Figure 4-3-1 shows the vertical structure of the NGM, with the thickness, in millibars, of each of the layers. We expect that by the end of 1990, the NGM output will entirely replace the use of the LFMII output for regional forecast products in the United States.

Spectral Model

Since 1980, NMC's Spectral model has run as the primary operational hemispheric and global prediction model. The model routinely uses 12 layers of the atmosphere (see figure 4-3-1) and, as of 1983, calculates out to 60 hours. Resolution is somewhat finer in the lower atmospheric levels than in the stratosphere, and the overall resolution of the model is slightly finer than that of the original LFM model. Instead of performing calculations in the horizontal in a grid, like the LFM, this model calculates "modes" of the atmosphere, which can be related to calculating the wave progression and amplitude changes of the waves in the atmosphere. Some parameters,

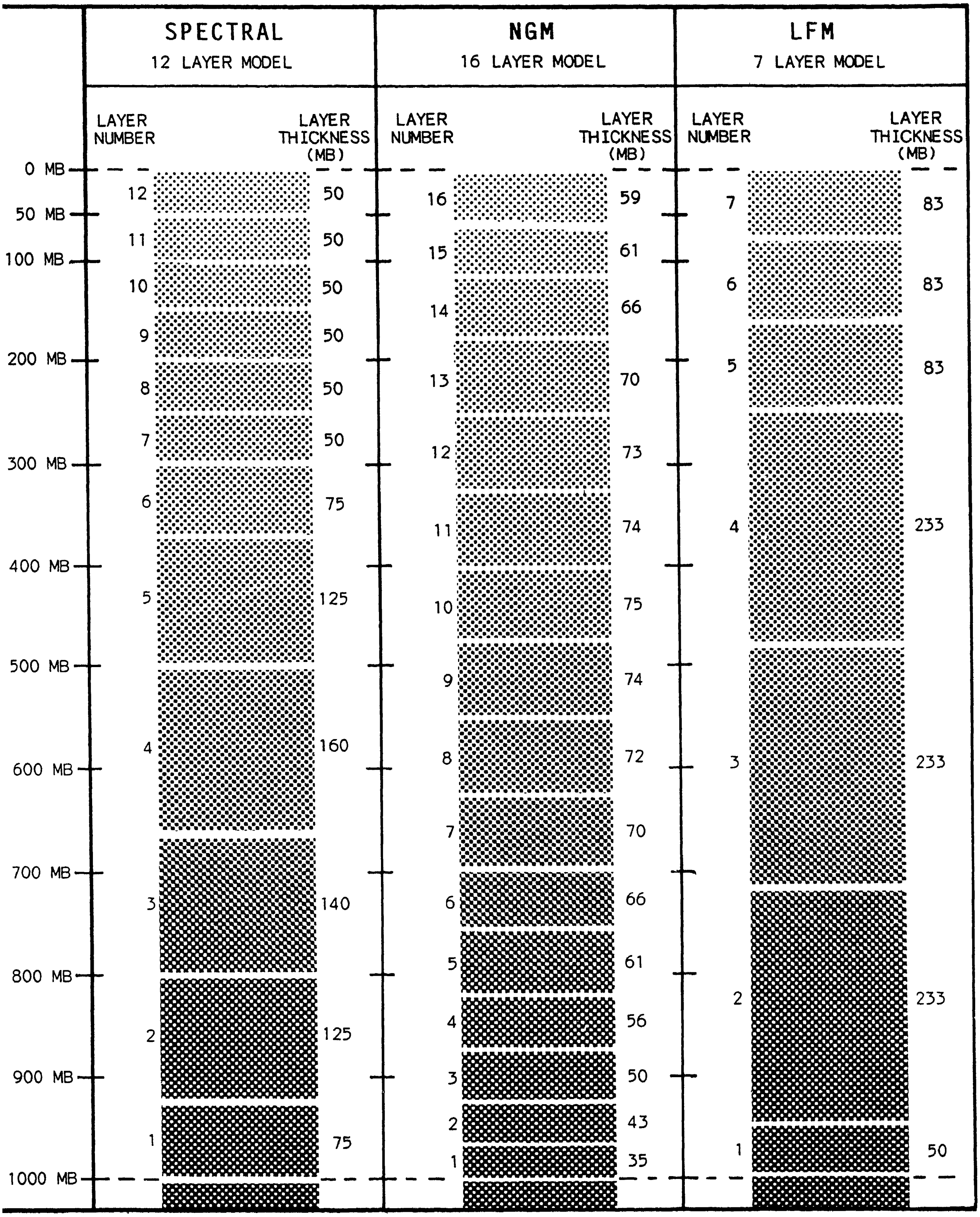


Figure 4-3-1.—Numerical prediction model layer structure comparison.

such as moisture, are calculated on an LFM-like grid. As of 1983, the Spectral model was only able to use 30 modes or waves in its calculations. In comparison, the LFM provides finer resolution. The Spectral model would require 40 to 45 modes to equal the LFMII model.

Three-Layer Global Model

To provide rapid computer calculations of the atmosphere for long-range forecasts, NWS uses the *NMC 3-Layer Global* model. This model performs calculations on three layers, from the surface to 150 millibars, and carries calculations routinely out to 11 days. The model output is primarily used for the 6- to 10-day forecasts. Although some accuracy is lost by performing calculations on fewer levels, this model is used because it requires much less computer processing time than the more complicated models with many layers.

Barotropic Mesh Model

Another forecast model is the *Barotropic Mesh Model.* It is used for rapid but fairly accurate calculations of certain situations out to 252 hours (10 1/2 days). This model assumes that the atmosphere is barotropic; that is, both pressure patterns and thermal patterns are in-phase (isoheights and isotherms are parallel), no thermal advection occurs, and there is no slope to pressure systems in the vertical. While this concept is invalid for most pressure systems, the model does handle certain systems better than the other models, which allow temperature changes due to advection. The Barotropic model output should always be used in conjunction with other model outputs to serve as a comparison and guidance for only the barotropic-like systems. It is good guidance for forecasting jet-stream movement.

LFM Model Output Statistics (LFM MOS)

Model Output Statistics (MOS) is a program that incorporates output from the LFMII model and compares this output with historical conditions since 1969 for a region or station to produce a forecast for that region or station. Different parameters are considered for the warm season (April through September) and the cool season (October through March). In some cases, the model distinguishes differences for four seasons. Output from the LFM MOS model is available in bulletin format out to 60 hours, citing best chances for maximum and minimum temperatures and probabilities for different types of weather occurrence, such as low ceilings, fog, and thunderstorms. Output is also available as a computer-worded forecast for a region or a specific location. It is also available as graphic charts out to 48 hours; these charts indicate various parameters for the United States, such as probability of precipitation, maximum and minimum temperatures, surface winds and winds aloft, and cloud cover.

NGM Model Output Statistics (NGM Perfect Prog)

Implemented in April 1987, the NGM Perfect Prog is very similar to the LFM MOS output in both graphics and bulletin products. The main difference is that Perfect Prog uses the forecast situation from the NGM model, vice the LFMII. The situation is then compared to the historical conditions, and probabilities for various types of weather occurrences are calculated. NGM Perfect Prog forecasts are referred to as *NGM Probability Forecasts* in some publications and product listings.

Learning Objective: Identify parameters on the most frequently used National Weather Service facsimile charts.

PARAMETERS ON NWS FACSIMILE CHARTS

Although the National Weather Service produces numerous facsimile charts to distribute oceanographic and meteorological information to its own forecast support offices, DOD, and public users, we cannot describe all of those charts in this training manual. To do so, we would need to publish a separate volume dealing with nothing but the NWS facsimile products. In this section we will discuss some of the most frequently used products.

Surface Analysis

The NWS's NMC produces four Northern Hemisphere surface analyses and eight North American surface analyses daily at synoptic and synoptic intermediate hours. All of these analyses are plotted and roughly analyzed by the computers, then reanalyzed by trained analysts. Figure 4-3-2 shows a typical section of a Northern

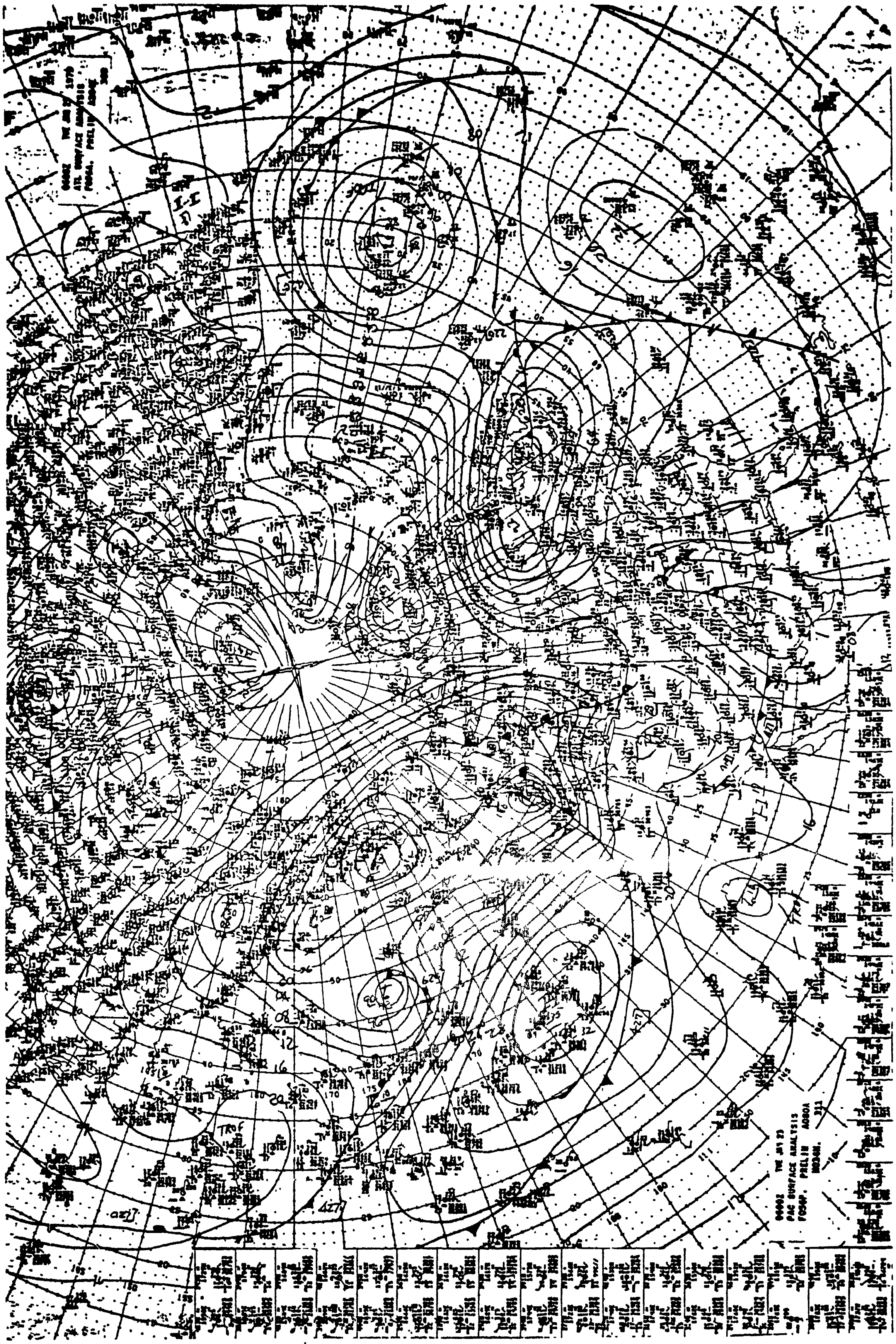


Figure 4-3-2.—NMC Northern Hemisphere Surface Analysis.

Hemisphere analysis as transmitted on facsimile. It is very similar to the North American analysis in the type of information presented.

The depiction and coding of various elements on these charts is as follows:

- Fronts and instability lines as indicated in figure 4-3-3. Frontal type, intensity, and character are indicated near each front in a three-digit code followed by a bracket (]). It may help you to remember this as the "TIC" code—for Type, Intensity, and Character—but these codes are actually World Meteorological Organization (WMO) codes 1152, 1139, and 1133, respectively. These codes are given in table 4-3-1. Pressure troughs are also labeled with the phonetic abbreviation *trof.*

- Plotted data for selected land, ship, and buoy stations as indicated in figure 4-3-3.

- *Isobars* (lines of equal pressure) are drawn as solid lines, usually using a 4-millibar interval and a base value of 1,000 millibars. Intermediate isobars may be shown as dashed lines. All isobars are labeled with two figures, for tens and units of millibars.

- Pressure centers are indicated by *H*s (for high pressure) and *L*s (for low pressure) with central pressure values given in two figures, for tens and units of millibars.

- Date and time of the analysis are printed in an identification block in the lower left (and upper right on the Northern Hemisphere analysis) corner of each chart.

Weather Depiction Analysis

The weather depiction analysis is a computer-plotted, computer-analyzed summary of aviation terminal conditions and is produced eight times a day—every 3 hours starting at 0100Z. It is designed to be primarily a briefing tool to alert aviation interests to the location of critical and near-critical operational minimums for the United States and surrounding land areas. Figure 4-3-4 shows a typical example of this chart.

The following information is depicted on each chart:

- Instrument Flight Rules (IFR) condition areas are enclosed by solid lines and are shaded. These are areas with ceilings below 1,000 feet and/or visibility below 3 statute miles.

- Marginal Visual Flight Rules (MVFR) condition areas are surrounded by a solid line but are not shaded. These are areas where the ceilings are between 1,000 and 3,000 feet and/or the visibility is between 3 and 5 statute miles inclusive.

Table 4-3-1.—Frontal Type, Intensity, and Character Codes

CODE	1152 - F_t - TYPE OF FRONT	1139 - F_i - INTENSITY OF FRONT	1133 - F_c - CHARACTER OF FRONT
0	Quasi-stationary front at the surface	No specification	No specification
1	Quasi-stationary front above the surface	Weak, decreasing (including frontolysis)	Frontal activity area decreasing
2	Warm front at the surface	Weak, little or no change	Frontal activity area little changed
3	Warm front above the surface	Weak, increasing (including frontogenesis)	Frontal activity area increasing
4	Cold front at the surface	Moderate, decreasing	Intertropical
5	Cold front above the surface	Moderate, little or no change	Forming or existence suspected
6	Occlusion	Moderate, increasing	Quasi-stationary
7	Instability line	Strong, decreasing	With waves
8	Intertropical Front	Strong, little or no change	Diffuse
9	Convergence line	Strong, increasing	Position doubtful

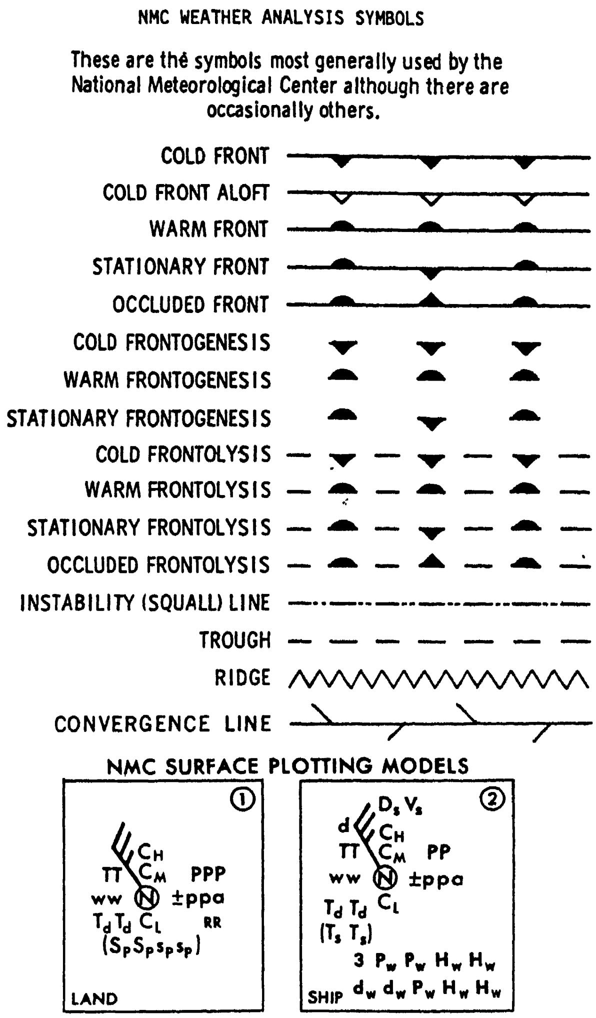


Figure 4-3-3.—NMC weather analysis symbols.

● Visual Flight Rules (VFR) condition areas prevail in all other areas not surrounded by solid lines. These are areas where the ceilings are greater than 3,000 feet and the visibility is greater than 5 statute miles.

● Surface frontal positions from the previous hour are drawn using the standard NMC depictions.

● Plotted data for each terminal includes (1) significant weather symbols; (2) visibility, in statute miles; (3) total sky cover, in tenths; and (4) ceiling height. All ceiling heights of the lowest layer with 5/10 or greater coverage are plotted. When total sky cover is less than 5/10, the height of the lowest scattered layer is plotted. Visibilities over 6 statute miles are not plotted.

● Date and time of the analysis are found in the identification block in the lower left corner of each chart.

Radar Summary

The Radar Summary chart is a computer analysis of digital radar reports and is used as mainly as a briefing aid. This chart is produced hourly from radar reports taken 35 minutes past each hour. Figure 4-3-5 shows an example of a typical Radar Summary.

The following information is routinely represented on radar summary charts:

● *Areas of radar-observed precipitation* are outlined with a solid line and shaded. *Isoecho* lines are drawn at levels 1, 3, and 5. Areas of light snow and drizzle usually do not show up well on radar and may not be indicated. Levels 3 and 5 contoured within the shaded areas indicate heavier precipitation.

● *Area movement*, or the movement of a general area of precipitation, is indicated by a wind barb showing the direction and speed of movement.

● *Cell movement*, or the movement of the strongest individual cumulonimbus cloud cell, is shown by an arrow indicating direction and a speed, in knots, printed near the point of the arrow.

● *Cloud cell tops* are indicated by three underlined digits representing the height, in hundreds of feet. A thin line is usually drawn from the end of the underline to a location within a shaded precipitation area to show the location of the measurement. *Cloud cell bases* are shown with three overlined digits.

● *Weather Watch areas* or boxes are enclosed with a dashed line and labeled with the watch number. The valid time of each watch area will be printed, along with the watch number, next to the legend in the lower left corner of each chart.

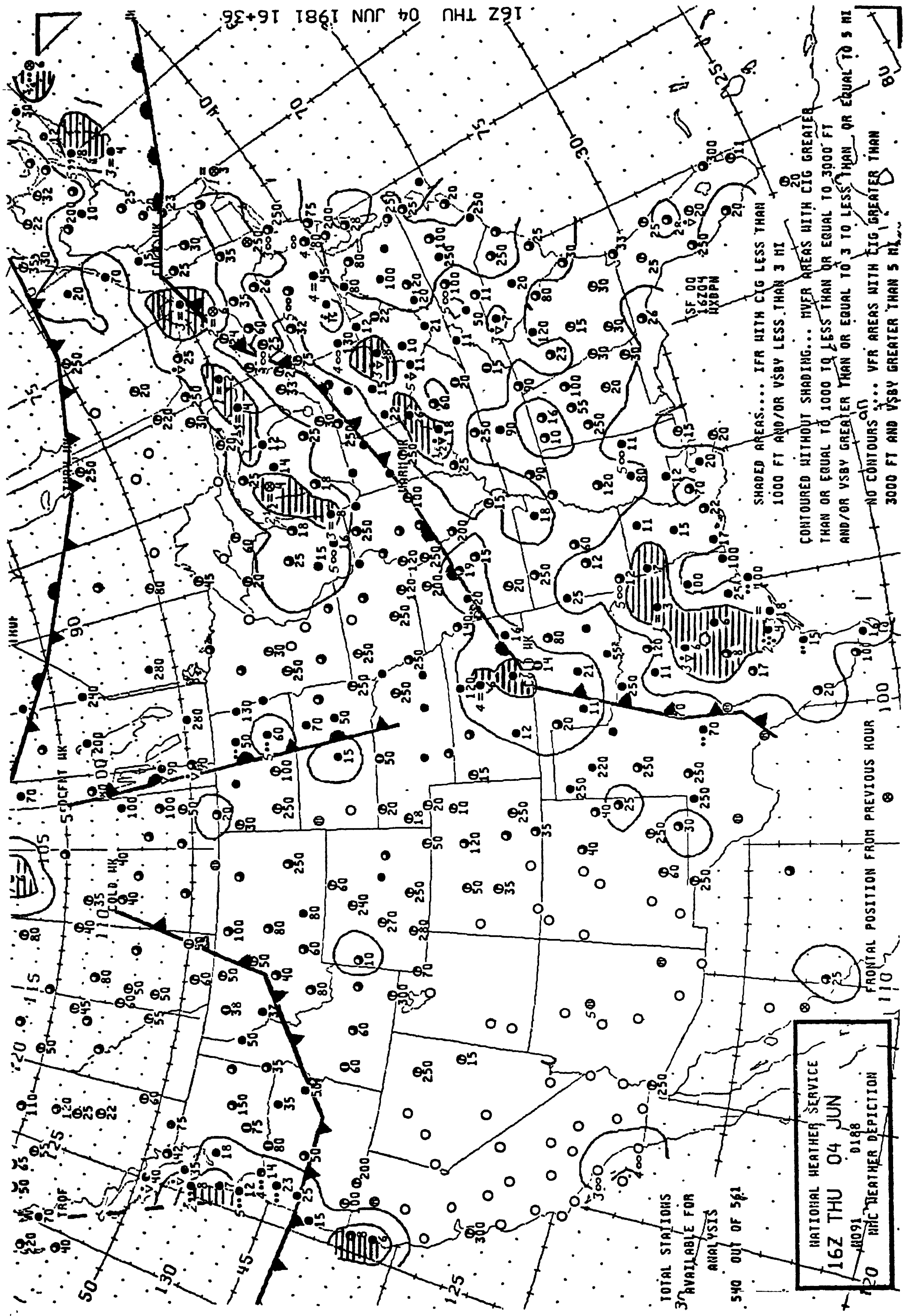


Figure 4-3-4.—Weather Depiction Analysis.

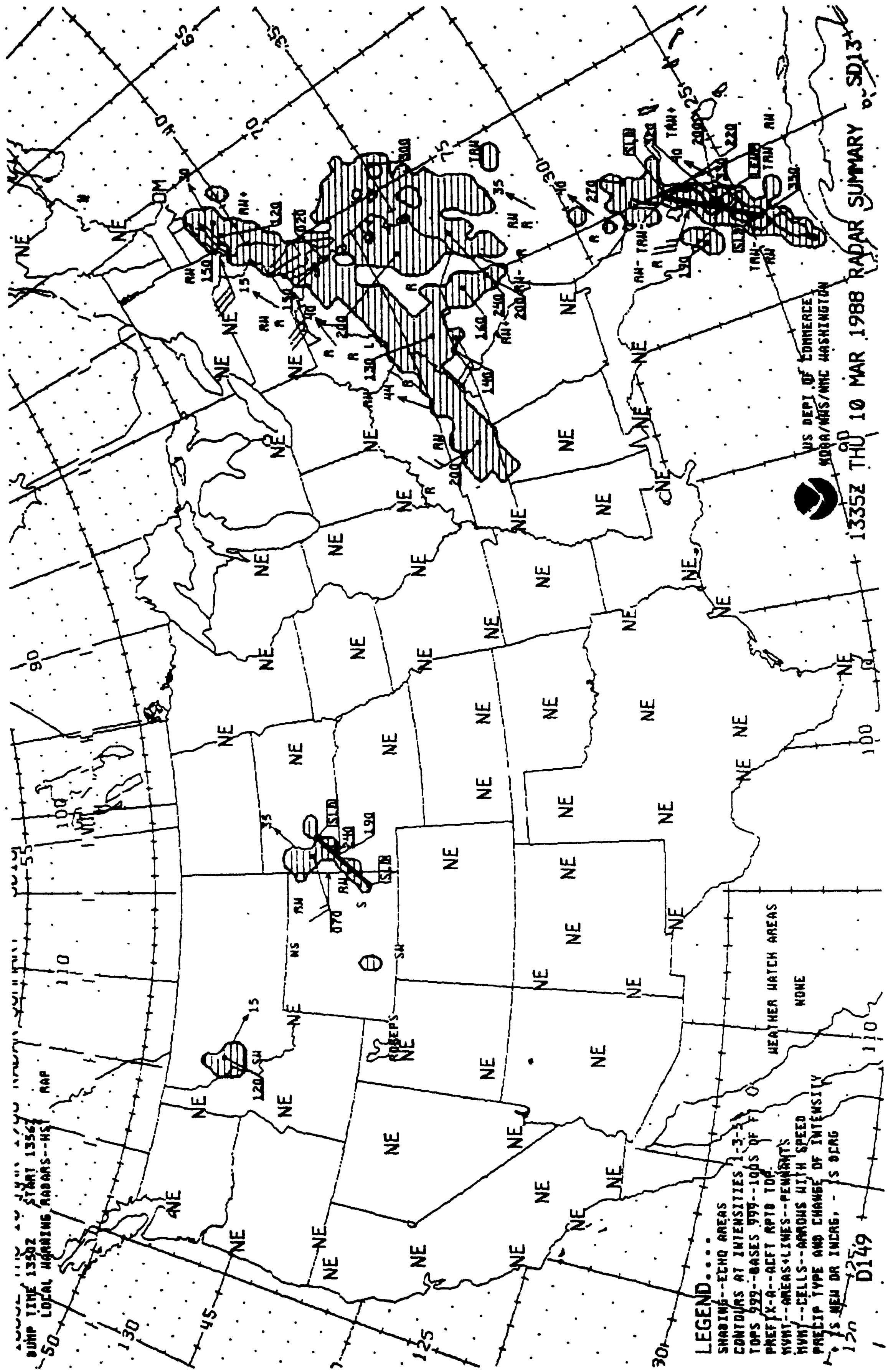


Figure 4-3-5.—Radar Summary Analysis.

• The following abbreviations are used on the charts to clarify reports or information:

R	Moderate Rain	S	Moderate Snow
RW	Rain Showers	SW	Snow Showers
ZL	Freezing Drizzle	ZR	Freezing Rain
–	Used after R, S, RW, SW, ZL, or ZR indicates light precipitation	+	Used after R, S, RW, SW, ZL, or ZR indicates heavy precipitation
TRW	Moderate Thunderstorms	TRW–	Weak Thunderstorms
TRW+	Heavy Thunderstorm	TRW++	Very Heavy Thunderstorm
TRWX	Intense Thunderstorm	TRWXX	Extreme Thunderstorm
TRWU	Thunderstorm, Intensity Unknown	LEWP	Line Echo Wave Pattern
SLD	Solid Line (Thunderstorms)	HOOK	Hook Echo (implies funnel cloud or tornado)
/+	(following any of above) intensity increasing	/–	(following any of above) intensity decreasing
NE	No echoes	OM	Radar out for maintenance
ROBEPS	Radar operating below established performance standards	NA	Report not available

• The valid time, date, and day of each chart are located in the lower right corner of the chart.

Upper-Air Analysis Charts

The NMC produces several upper-air analysis charts twice daily, at 0000Z and 1200Z. All are done by the computers with limited analyst intervention. Output from the computer may be grouped into two general categories: the North American charts, with plotted data, and the Northern Hemisphere charts, without plotted data. Figure 4-3-6 shows a typical North American upper-air analysis with plotted data. The North American charts are routinely available for the standard levels 850, 700, 500, 300, and 200 millibars. The Northern Hemisphere charts are produced for the 500- and 300-millibar levels.

These upper-air analyses are sometimes referred to as *constant pressure* charts. The differences in air density/thickness are shown by *isoheight* lines, or lines of equal height of a constant pressure surface above mean sea level.

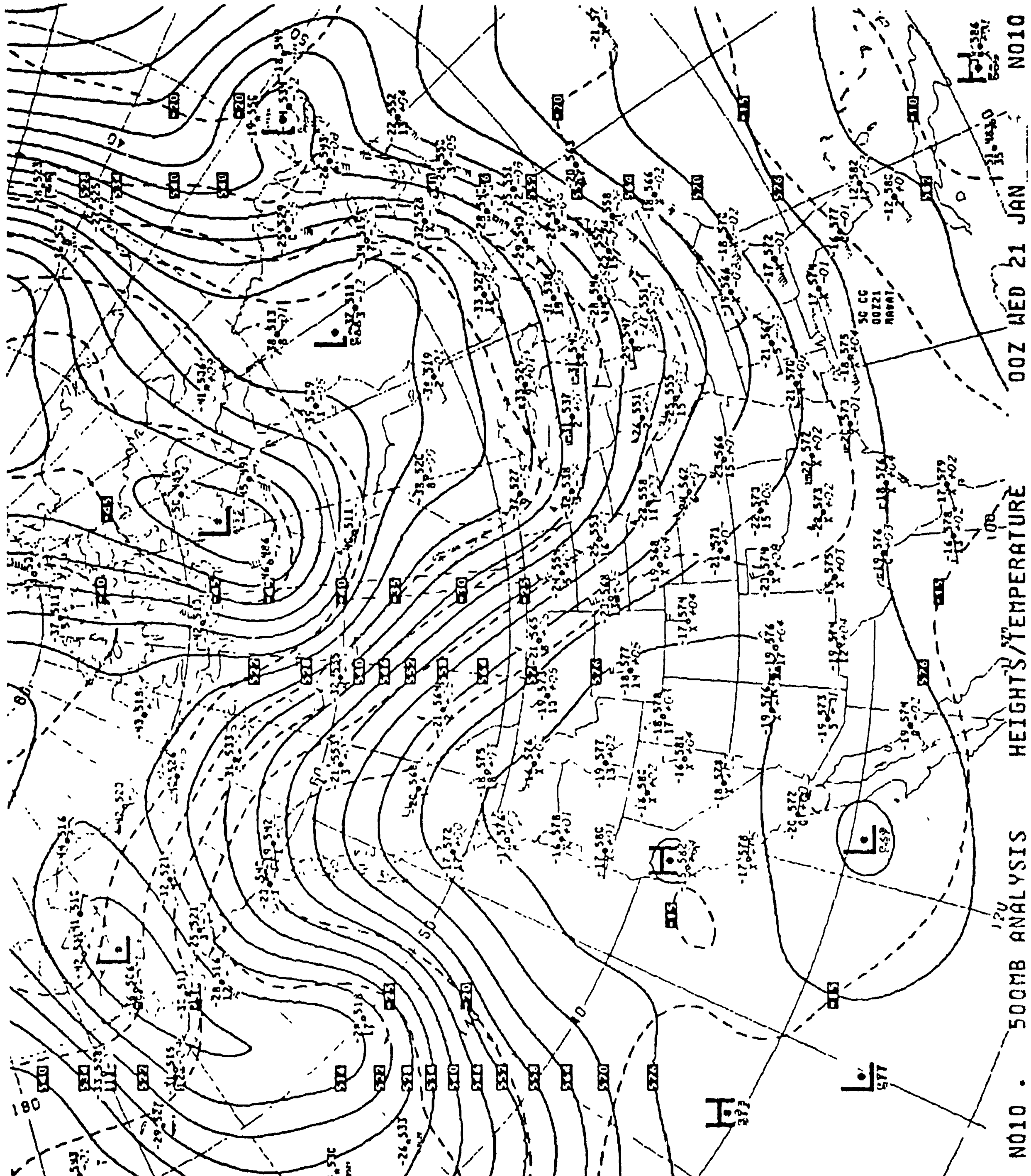


Figure 4-3-6.—Upper Air Analysis.

The different parameters shown on these charts are as follows:

- Isoheight contours are shown by solid lines. Table 4-3-2 shows the approximate height of each chart, the base height of the isoheight lines, and the standard contour spacing of the isoheight lines. Each isoheight and height center are labeled in thousands, hundreds, and tens of meters.

- Although troughs and ridges are shown by the isoheight contours, the placement of axis lines for these features is left to the user. Since the computer draws smooth isoheight contours, reanalysis of the contours may help locate the axis of troughs, especially short-wave troughs. This, of course, is not possible on the charts that do not display the plotted data. (Review *AG2*, Volume 1, Unit 8, Lessons 2 and 3, if necessary for relative information.)

- *Isotherms*, or lines of equal temperature, are shown every 5 °C by dashed lines and labeled with the temperature. The computer tends to over-smooth the isotherms. Reanalysis of isotherms sometimes shows isotherm troughs much better than the computer analysis. This is important when attempting to identify short waves in the isoheight analysis. Isoheight troughs are usually associated with isotherm troughs, although the isotherm and isoheight trough axes may not necessarily coincide.

- High and low height centers are indicated by *H*s and *L*s respectively, and are labeled with three digits to indicate the central height.

Table 4-3-3.—Significant Moisture on Constant Pressur Charts Based on a 3 °C Frost Point Depression

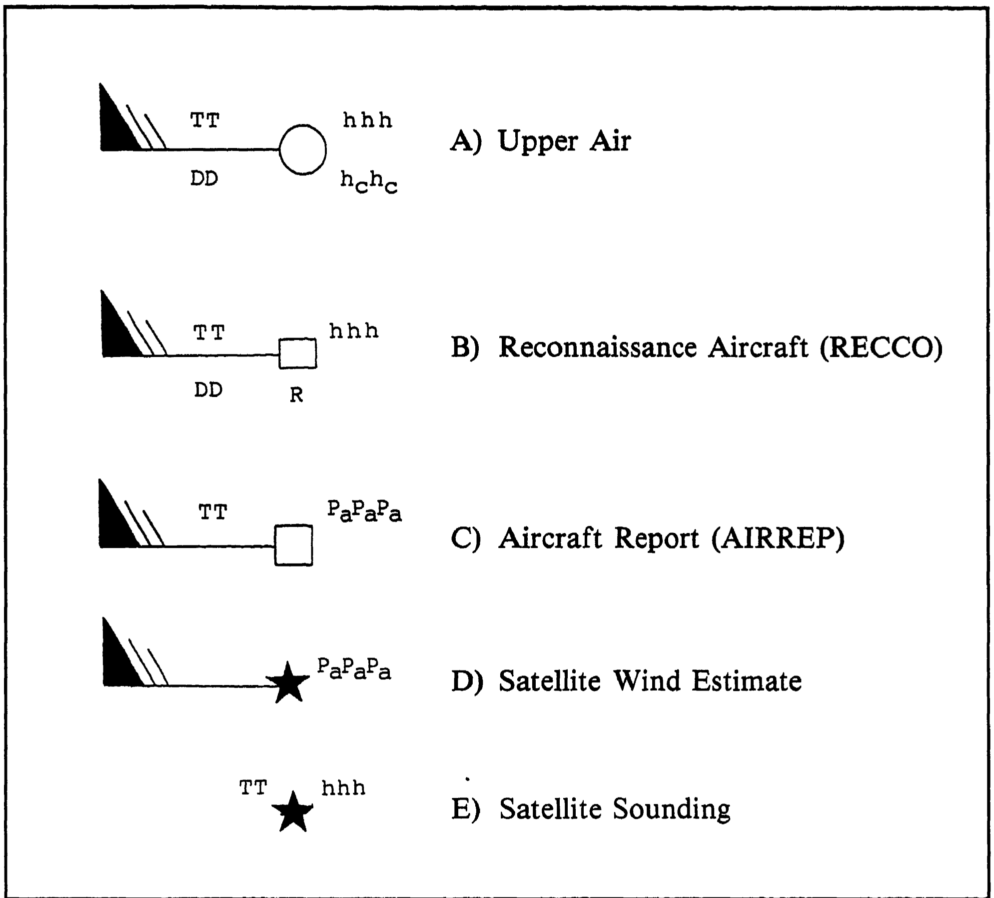
TEMPERATURE RANGE °C	DEW-POINT DEPRESSION °C
>−5	3
−6 to −14	4
−15 to −24	5
−25 to −34	6
−35 to −44	7

- Plotted data on the North American chart is depicted on the charts according to the plottin models in figure 4-3-7. Station circles are fille in when the dew-point depression is equal to o less than 5 °C. Reanalysis of significant moistur at the standard levels should be done by criteri in table 4-3-3 to depict where significant moistur exists (enough moisture to form broken to over cast cloud cover).

- *Isotachs*, or lines of equal wind speed, ar shown as dashed lines at 20-knot intervals on bot the 300- and 200-millibar charts, with areas o wind speeds 50 to 110 knots being shaded. Furthe analysis should be done to find the jet-stream axi

Table 4-3-2.—Isoheights on Constant Pressure Charts

PRESSURE (millibars)	APPROXIMATE HEIGHT (feet)	BASE HEIGHT (meters)	CONTOUR SPACING (meters)
850	5,000	1,470	30
700	10,000	3,000	60
500	18,000	5,580	60
300	30,000	9,120	120
200	39,000	11,820	120



TT is temperature in whole degrees Celsius.

hhh is height of constant pressure in:

- Meters on 850 and 700 mb charts
- Tens of meters on 500, 300, and 200 mb charts.

$P_a P_a P_a$ is pressure altitude of the observation in hundreds of feet.

DD is dew-point depression in whole degrees Celsius. "X" replaces DD when the depression exceeds −29 °C.

R is RECCO type

Figure 4-3-7.—Upper-air chart plotting models.

and jet-stream maximum wind speed (jet-max) areas. The location of the jet-streams and changes in their location and orientation are very important factors in many different types of forecasts, such as, but not limited to, frontal movement, pressure system development and movement, turbulence, and cirrus cloudiness.

Composite Chart

The composite chart is a computer-plotted, hand-analyzed four-panel chart consisting of a Lifted Index/K Index analysis, precipitable water analysis, freezing level analysis, and average surface-to-500-millibar relative

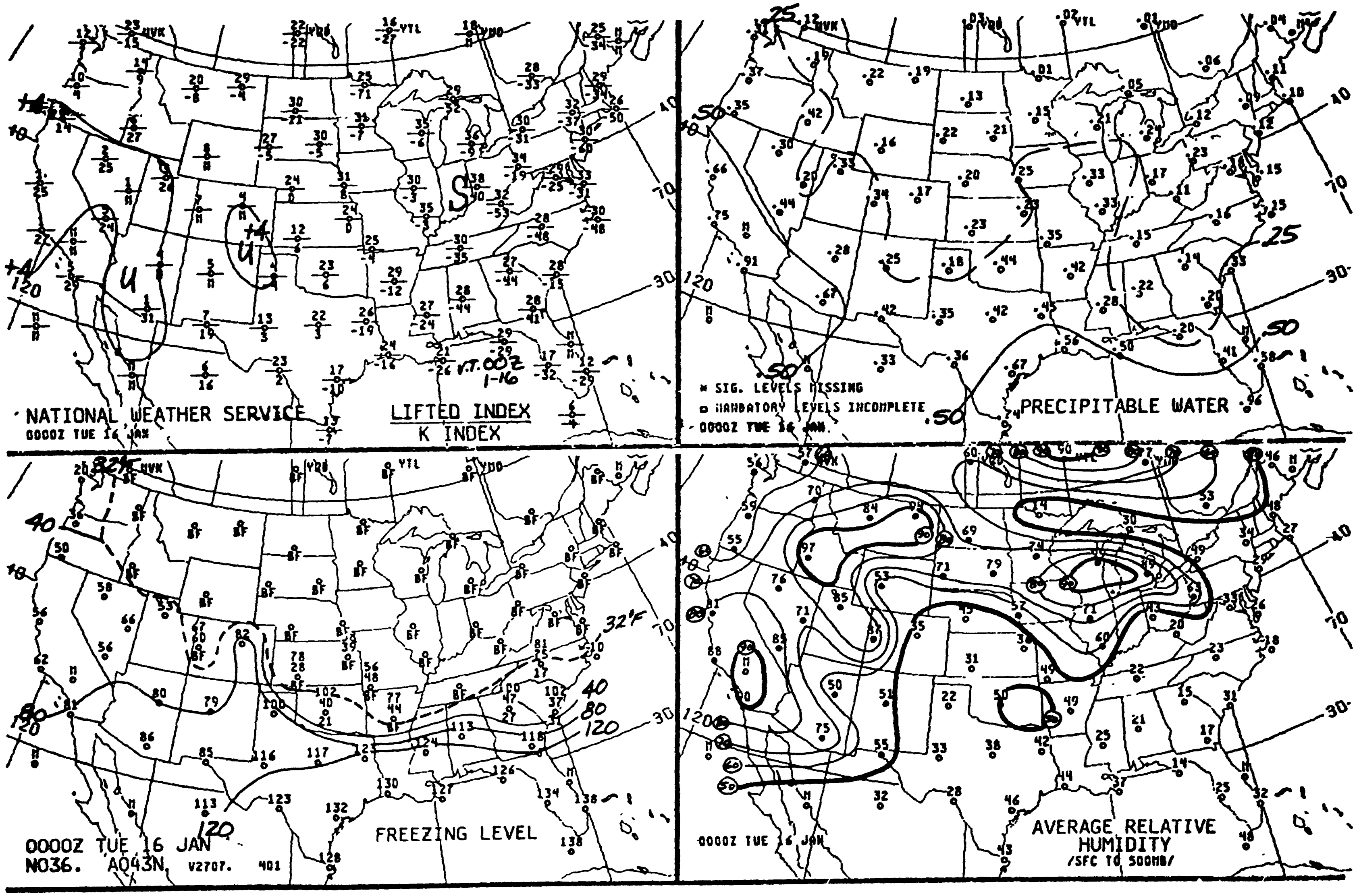


Figure 4-3-8.—Composite Analysis.

humidity analysis. These panels are shown in figure 4-3-8.

LIFTED INDEX/K INDEX PANEL.—Values for both the Lifted Index (layer method) and the K Index are plotted for every reporting upper air station in the continental United States, southern Canada, and northern Mexico. The Lifted Index is plotted over the station circle and the K Index below the circle. An analysis of the Lifted Index is represented by solid lines separating the stable areas, marked with an *S*, from the unstable areas, marked with a *U*. An *M* is plotted for both missing data and data that cannot be computed because the station is on a high mountain. Additional information on the Lifted Index and the K Index is presented in Unit 6, Lesson 2. This information is used to forecast convective weather.

PRECIPITABLE WATER.—The amount of precipitable water in a column of air for each reporting station is plotted in inches. Solid lines are drawn for each half inch of water; dashed lines, for every quarter inch if necessary. Station circles are darkened for all areas exceeding 1 inch of precipitable water. This information is used as a base value in forecasting rainfall and snowfall amounts.

FREEZING LEVEL.—The heights of up to three freezing levels are plotted, in hundreds of feet, for each reporting station. Solid lines labeled in hundreds of feet represent the isoheight of the lowest freezing level above ground level (AGL) in intervals of 4,000 feet, while a dashed line labeled *32*°F represents the surface freezing isotherm. Stations with the surface temperature below freezing will show "BF" as the lowest freezing level. The heights, the number of freezing levels, and location of warm layers overlapping freezing layers are all important information in analyzing and forecasting icing conditions and precipitation type.

AVERAGE RELATIVE HUMIDITY.—Plotted values are the calculated average-relative-humidity percentages from the surface to 500 millibars. Thin solid lines are drawn for percentages from 60% to 80% and labeled, while thick solid lines are drawn for 50% and 90% humidity. Lines of equal humidity are called *isohumes*. The surface-to-500-millibar humidity is an important factor in convective weather and severe-weather forecasting. It is also used as a general guideline in estimating cloud coverage.

12-Hour Upper-Wind Chart

The eight-panel, 12-hour upper-wind chart, shown in figure 4-3-9, is transmitted twice daily after it has been calculated by the 7-layer Primitive Equation model. Twelve-hour wind forecasts and temperature forecasts are provided for 6, 9, 12, 18, 24, 30, 34, and 39 thousand feet above mean sea level (MSL). Wind direction and speed are indicated using a standard wind barb, with the tens value of the wind direction entered as a single digit near the wind feathers. The temperatures are indicated by two digits representing the temperature in degrees Celsius above the station location. This same data is also sent out in bulletin format, known by the MANOP as *FD* (for forecast upper-level winds) bulletins.

Both the chart and the bulletins are frequently used at our aviation weather offices to obtain flight level winds for flights within the continental United States.

Boundary Layer Wind/ Relative Humidity Chart

The boundary layer wind and relative humidity chart is produced twice daily from the 1200Z and 0000Z data cycles by the LFMII model. A typical chart is shown in figure 4-3-10. In the very near future, this product is expected to be produced by the NGM model. Four charts are produced in each cycle, for the 12-, 24-, 36-, and 48-hour forecasts. The chart background covers much of North America, as well as portions of the eastern Pacific, western Atlantic, and western Caribbean. The wind speed and direction are represented by standard wind barbs, with the tens unit of the direction plotted near the feathers. The LFM model calculates the winds for its boundary layer at 1,500 feet above the surface. Use of the NGM model will result in wind forecasts at approximately 986 feet above the surface, the boundary layer of the NGM. Relative humidity percent is plotted at the focus of each report except that no values are plotted for the far left side of the chart, which is not covered by the LFMII's moisture grid. However, the NGM's grid C extends farther west and should correct that situation. The valid time, date, and chart identification are printed across the bottom of each chart, as well as in a cryptic ID block in the central Gulf of Mexico.

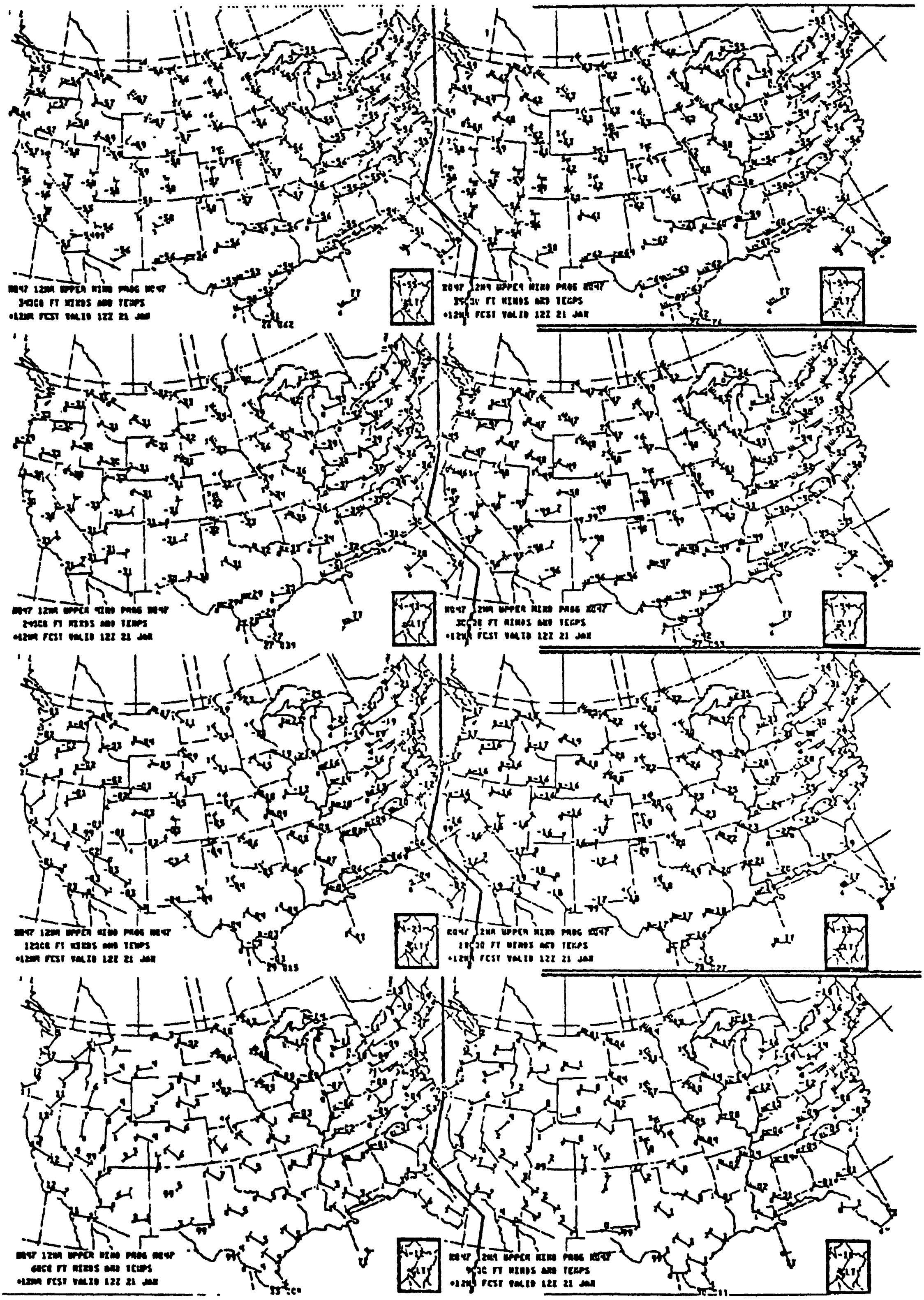


Figure 4-3-9.—12-hour Upper-Wind Prognosis chart.

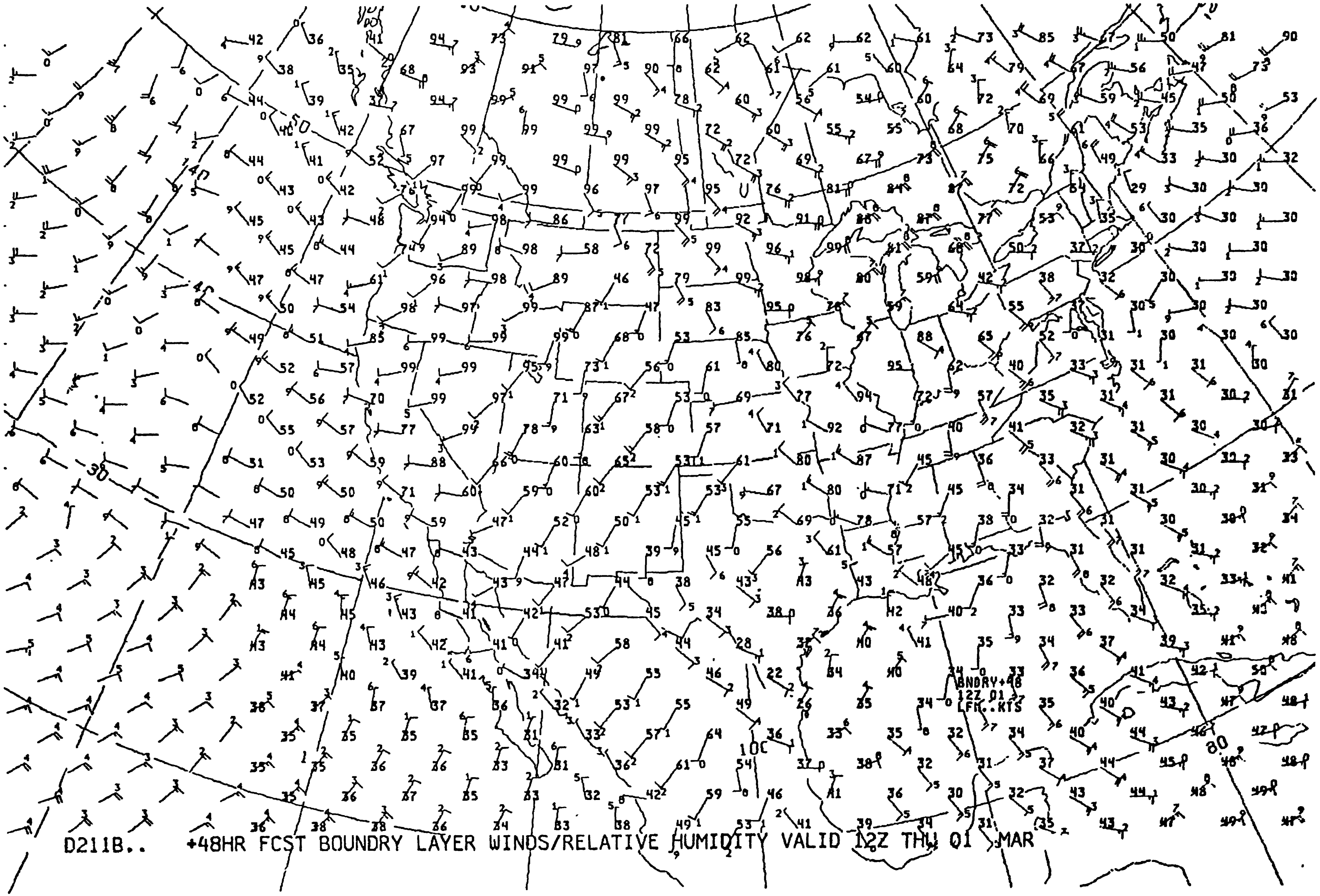


Figure 4-3-10.—Boundary Layer Wind/Relative Humidity Prognosis chart.

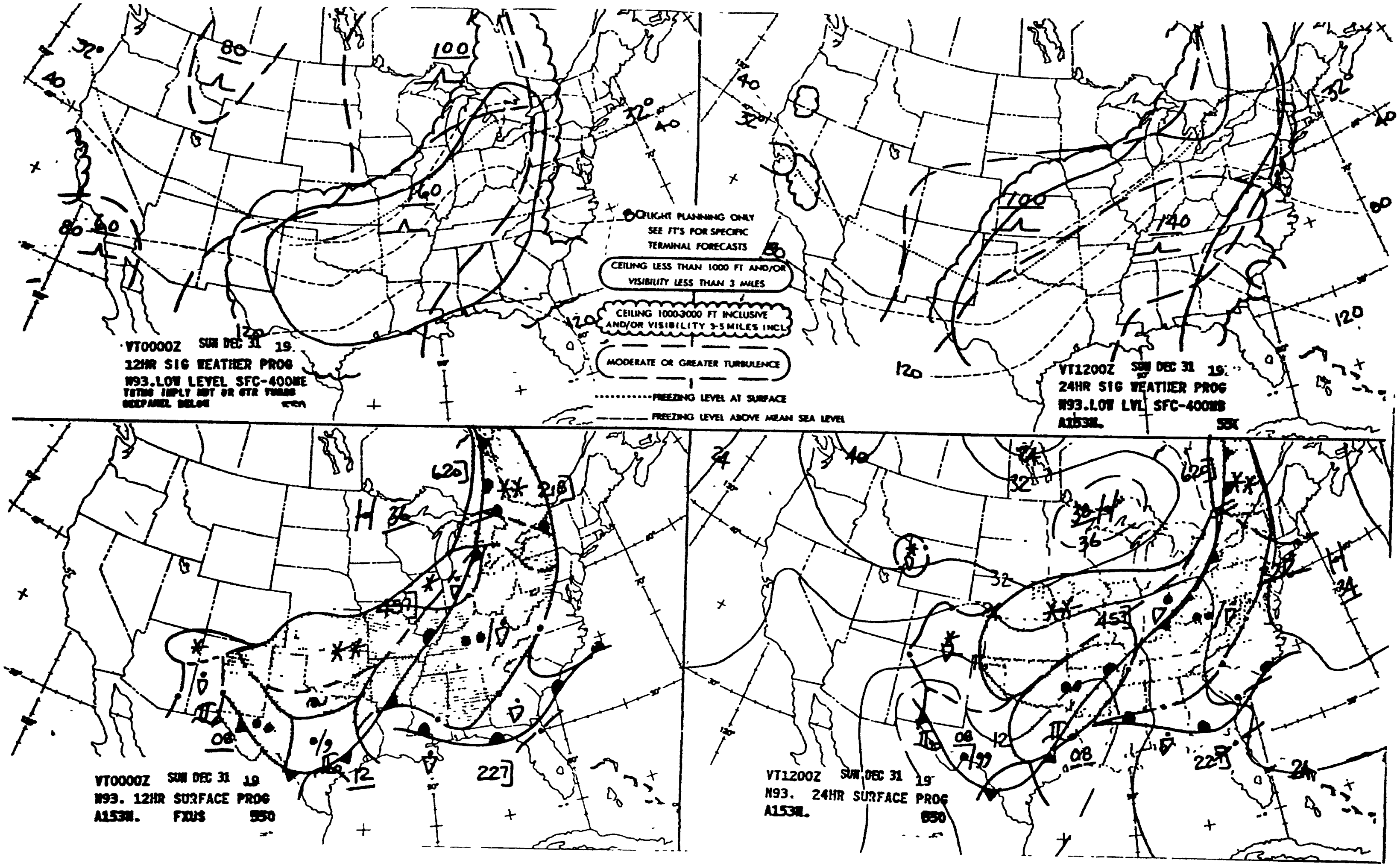


Figure 4-3-11.—12- and 24-hour Surface Weather Prognosis chart.

These charts are frequently used, with some adjustment, to forecast surface winds.

Surface Weather Prognostic Charts

The surface weather prognostic charts provide depictions of various surface weather features and significant weather (low-level-flight weather) features out to 48 hours. They are manually produced forecasts, produced with guidance from the LFMII, NGM, and other numerical products. The 12- and 24-hour forecasts (shown in figure 4-3-11) are presented on one chart produced four times a day with both a surface weather prognostic panel and a significant weather features (Sig Wea) panel for each forecast time. The 36- and 48-hour forecasts are on a second chart (shown in figure 4-3-12) produced twice daily, with only a single panel showing combined surface and significant weather features. These charts are frequently used as briefing aids and are displayed in just about every stateside weather office. The following information may be depicted on some or all of these charts. (The charts on which the information appears are within parentheses after the information.)

- Frontal type and position, using the standard symbols presented in figure 4-3-3. (all surface progs)

- High and low pressure centers are indicated by *H*s and *L*s, with the pressure value (underlined) to the nearest whole millibar. (all surface progs)

- Pressure center movement is indicated by an arrow for direction, and the forecast speed of movement at the valid time of the chart is entered, in knots, at the head of each arrow. The term *STNRY* is used to indicate little movement. (24, 48 surface progs)

- Isobars may be depicted with a thin solid line and an 8-millibar interval, and labeled in tens and units of millibars. (24, 36, 48 surface progs)

- Frontal type, intensity, and character codes, explained previously. (all surface progs)

- Areas of noncontinuous precipitation (intermittent precipitation or showers) affecting less than one-half of the area are enclosed by a long-dash-dot line (____ . ____ .) surrounding an appropriate weather symbol. Weather symbols used are standard present weather symbols for intermittent/showery precipitation. (all surface progs)

- Areas of noncontinuous precipitation affecting one-half or more of the area are surrounded by a long-dash-dot line and are shaded. (all surface progs)

- Areas of continuous precipitation are surrounded by a bold solid line (________) and are shaded if one-half or more of the area will be affected (or are not shaded if less than one-half of the area will be affected). (all surface progs)

- Areas of liquid and freezing/frozen precipitation are separated by a bold dashed line (____ ____). (all surface progs)

- Freezing levels are indicated by fine short-dash lines (__ __ __ __) and are labeled with the height, in hundreds of feet. (12, 24 Sig Wea prog)

- The surface 32 °F isotherm is depicted with a dotted line (. . . . . . .) and is labeled. (12, 24 Sig Wea prog)

- Areas of moderate or greater turbulence from the surface to 24,000 feet are surrounded by a bold long-dash line (_____ _____ _____). The appropriate turbulence symbol and the height of the base (overlined) and the tops underlined) of the turbulence are written within or near the area. (12, 24 Sig Wea prog)

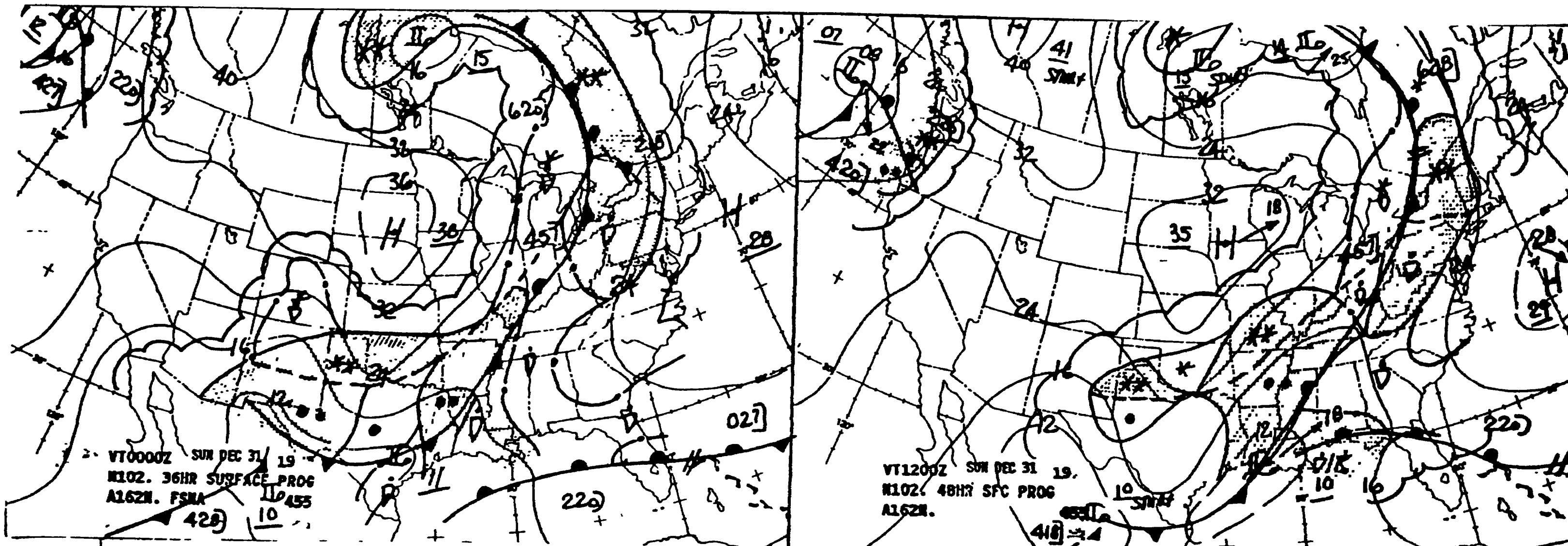
- Areas of forecast IFR terminal conditions are surrounded by a bold solid line (________). (12, 24 Sig Wea prog)

- Areas of forecast MVFR terminal conditions are surrounded by a bold scalloped line ( ). (12, 24 Sig Wea progs and 36, 48 surface progs)

- A forecast discussion about which guidance was used and why it was used is written in plain language with many abbreviations. (34, 48 surface prog)

The NGM Prognostic Chart Series

The NGM prognostic chart series has effectively replaced the LFM chart series as of this



Prog discussion based on 12Z Dec 29, 1978 data
Re Fax NO. 93 and 102.

The LFM was not available for guidance with Fax 93
Trof now south of Aleutians is fcst to mov south of east thru prog series. This wl not pose threat to w cst of US until 48 hrs By that time there should be enough overrunning to produce snow in wrn OR. This implies LFM is slightly slow

The trof now sw of CA is fcst to move ewd ovr Mex in 48 hrs. Pcpn expctd srn AZ in 12 to 24 hrs with ewd spread into NM and w TX. As cld fnt moves off TX cst in 36 hrs sfc wv formation is expected in Gulf. However, wv wl not develop much until trof to the west moves further east than fcst in 48 hrs. At that time low wl accelerate newd and deepen.

Vort continues to rotate arnd major trof now cntrd ovr swrn Can. Thus cld fnt wl continue to move ewd and LFM pcpn area ahead of fnt not moved fast enough into Ohio vly and too much pcpn is retained Grt plns but otherwise acceptable.

Modified progs prefer to hold on to fnt now south of FL and move it nwd as wrm fnt Thus modified progs add pcpn to LFM se cst and n of fnt in FL. Combs

Figure 4-3-12.—36- and 48-hour Surface Weather Prognosis chart.

writing. This series consists of a set of four charts, or panels, for each forecast time: 12, 24, 36 and 48 hours. An example of the 48-hour forecast set is shown in figure 4-3-13. The charts or panels consist of (1) the 500-millibar heights and vorticity panel, (2) the mean sea level pressure and 1,000-to-500-millibar thickness forecast, (3) the 700-millibar height and relative humidity forecast, and (4) the precipitation and 700-millibar vertical velocity forecast. These four panels may be sent on one chart, as in the example, or individually. The series is produced twice each day from the 0000Z and 1200Z data collections.

500-MILLIBAR HEIGHTS AND VORTICITY.—On this panel the 500-millibar isoheights are depicted with solid lines and labeled in decameters. Absolute vorticity is depicted with dashed lines every 2×10^{-5} units per second and labeled 2, 4, 6, etc. Areas of relative vorticity maxima are indicated by an *X,* while areas of relative vorticity minima are indicated by an *N.*

Since *vorticity advection* is often more important in forecasting than is the vorticity value, you may find it helpful to do your own vorticity advection analysis. You do this by drawing in the axes of minimum vorticity values through the *N*s (the vorticity troughs) and the axes of maximum vorticity through the *X*s (the vorticity ridges).

Any area on the downwind side of a vorticity ridge, where the vorticity pattern is not parallel

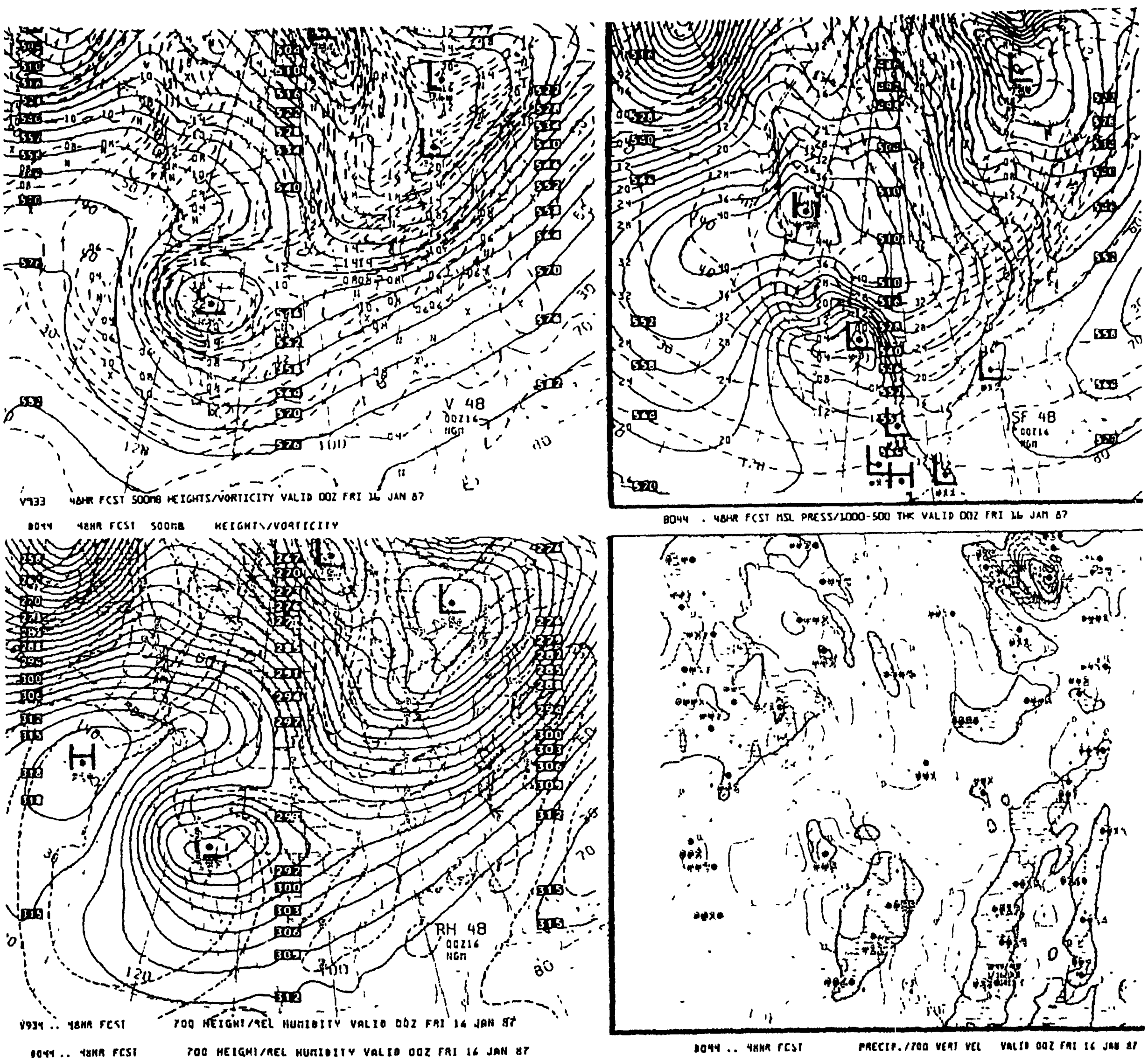


Figure 4-3-13.—NGM prognosis chart.

to the height contours, is an area of *positive vorticity advection*. Typically, these areas are shaded in red pencil. Positive vorticity advection shows a tendency for the air to increase its upward velocity. This means that clouds will tend to form or become thicker and that precipitation will tend to begin or become heavier/more widespread.

Any area on the downwind side of a vorticity trough, where the vorticity pattern is not parallel to the isoheights, is an area of *negative vorticity advection*. These areas are lightly shaded in blue pencil. Negative vorticity advection tends to slow the upward vertical velocity or increase a downward vertical velocity (subsistence). It tends to decrease precipitation coverage and intensity and to dissipate cloudiness.

Vorticity ridges, sometimes called vorticity maxima lobes, tend to overlie short-wave troughs. These may be more evident on the lower level 700-millibar isoheight forecast as height troughs or on the surface forecast as a pressure trough (frontal or non-frontal).

MEAN SEA LEVEL PRESSURE AND 1,000-TO-500-MILLIBAR THICKNESS FORECAST.—Isobars are drawn with solid lines every 4 millibars and labeled in tens and units of millibars. Surface high-pressure centers are labeled with an *H*, and low centers with an *L*. An *X* within a circle indicates the exact forecast center position. The 1,000-to-500-millibar-layer thickness is indicated with dashed lines every 60 meters and is labeled in decameters.

Thickness contours and isobar patterns should greatly assist you in your determination of frontal placement on these forecast charts. Thickness lines are closer together (packed) on the cold-air side of warm and cold fronts, which lie in the troughs of low pressure. Slight bends in the thickness pattern can indicate a pressure trough or a very weak frontal system. A large bulge in the thickness pattern either parallel to the surface isobars or toward lower pressure usually indicates an occlusion.

700-MILLIBAR HEIGHTS AND RELATIVE HUMIDITY.—On this panel, the 700-millibar isoheights are drawn in solid lines every 30 meters and are labeled in decameters. High and low height centers are labeled in decameters as well. The average surface-to-500-millibar relative humidity values are drawn in dashed lines from 10 to 90 percent. Values greater than 70 percent are shaded. Short-wave determination is best done on this chart, using the vorticity forecast as a guide.

700-MILLIBAR VERTICAL VELOCITY AND PRECIPITATION.—On this panel, the thin solid lines indicate vertical velocity, or the upward/downward movement within a column of air. Isopleths are drawn every 3 microbars per second, and labeled in microbars. A positive value means the air is rising, while a negative value means the air is sinking. A microbar is a unit of pressure (0.001 millibar). A 3-microbar-per-second vertical velocity equates roughly to air rising at 0.11 feet per second (near 700 millibars).

The bold solid lines indicate forecast precipitation accumulations for the 12-hour period ending at the forecast time (valid time) of the chart. Although these lines are not labeled, they are drawn at 1/2-inch intervals starting at a trace. The area between alternate contours is shaded so that shading represents accumulated precipitation from a trace to 1/2 inch, 1 inch to 1 1/2 inches, 2 to 2 1/2 inches, etc. Additionally, relative precipitation maximum centers are identified with an *X* within a circle and are labeled in hundredths of an inch. Precipitation amount is the only time-phased parameter on the NGM chart series.

MOS Probability Charts

Information from the Model Output Statistics program is available as mapped charts or bulletins. Three of the most used charts are the 24-to-60-hour maximum and minimum temperature forecasts (fig. 4-3-14), the 12-to-30-hour surface wind and cloud amount forecast (fig. 4-3-15), and the 12-to-48-hour probability of precipitation and precipitation-type forecast (fig. 4-3-16). All of the MOS products are produced twice daily from the 0000Z and 1200Z data bases. We will discuss the breakdown of the bulletins in the following section.

MOS MAXIMUM AND MINIMUM TEMPERATURE FORECAST.—This chart shows four panels of maximum or minimum temperature forecasts, at 24, 36, 48, and 60 hours. Forecast temperatures are plotted in degrees Fahrenheit for most major cities across the United States. Isotherms are drawn every 10 °F, as well.

SURFACE WIND AND CLOUD AMOUNT FORECAST.—The four panels of this chart are valid 12, 18, 24, and 30 hours from the data base time. On this computer-plotted chart, station

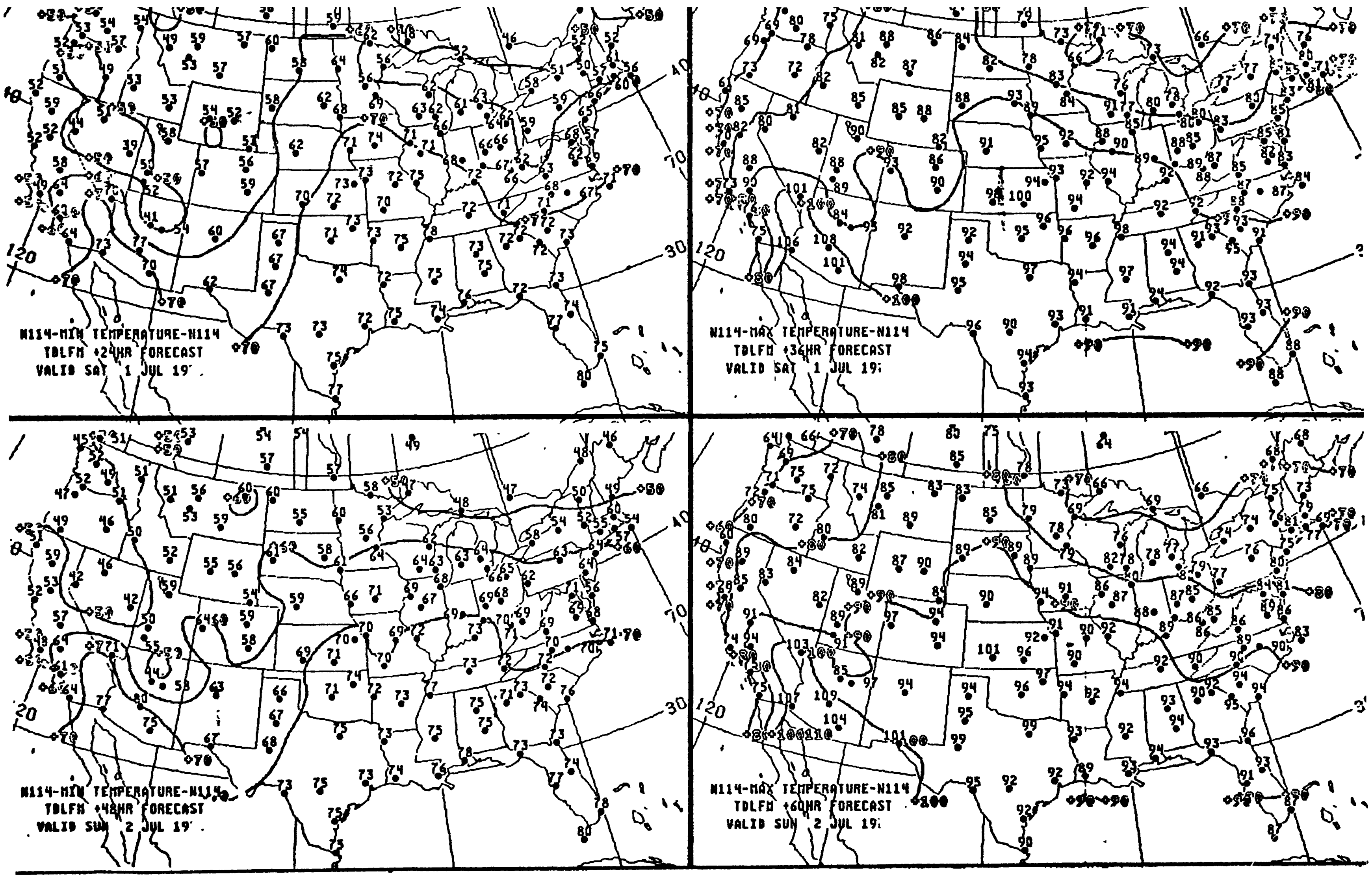


Figure 4-3-14.—MOS 24-to-60-hour Max/Min Temperature Prognosis chart.

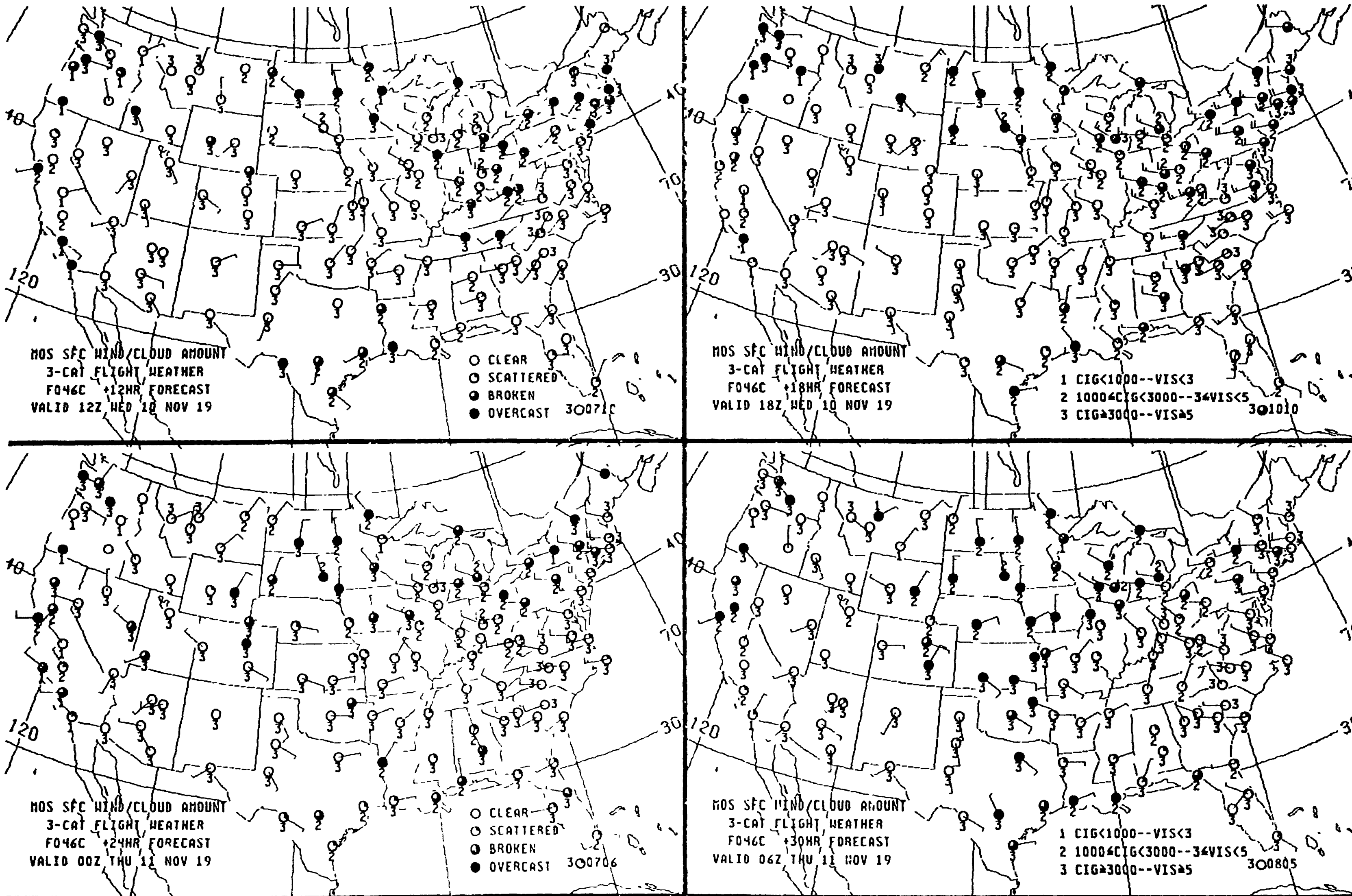


Figure 4-3-15.—MOS 12-to-30-hour Surface Wind/Cloud Amount Prognosis chart.

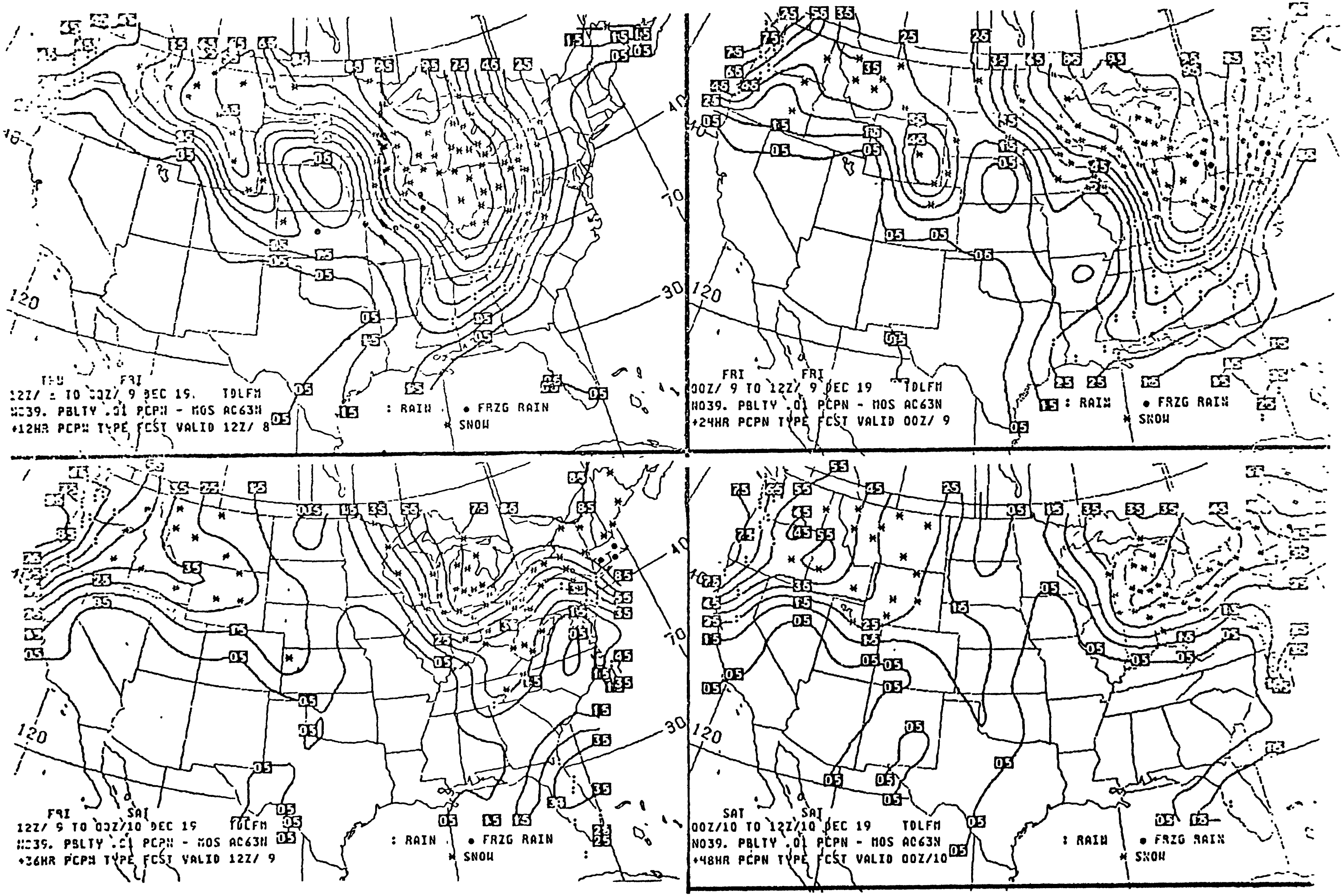


Figure 4-3-16.—MOS 12-to-48-hour POP/Precip Type Prognosis chart.

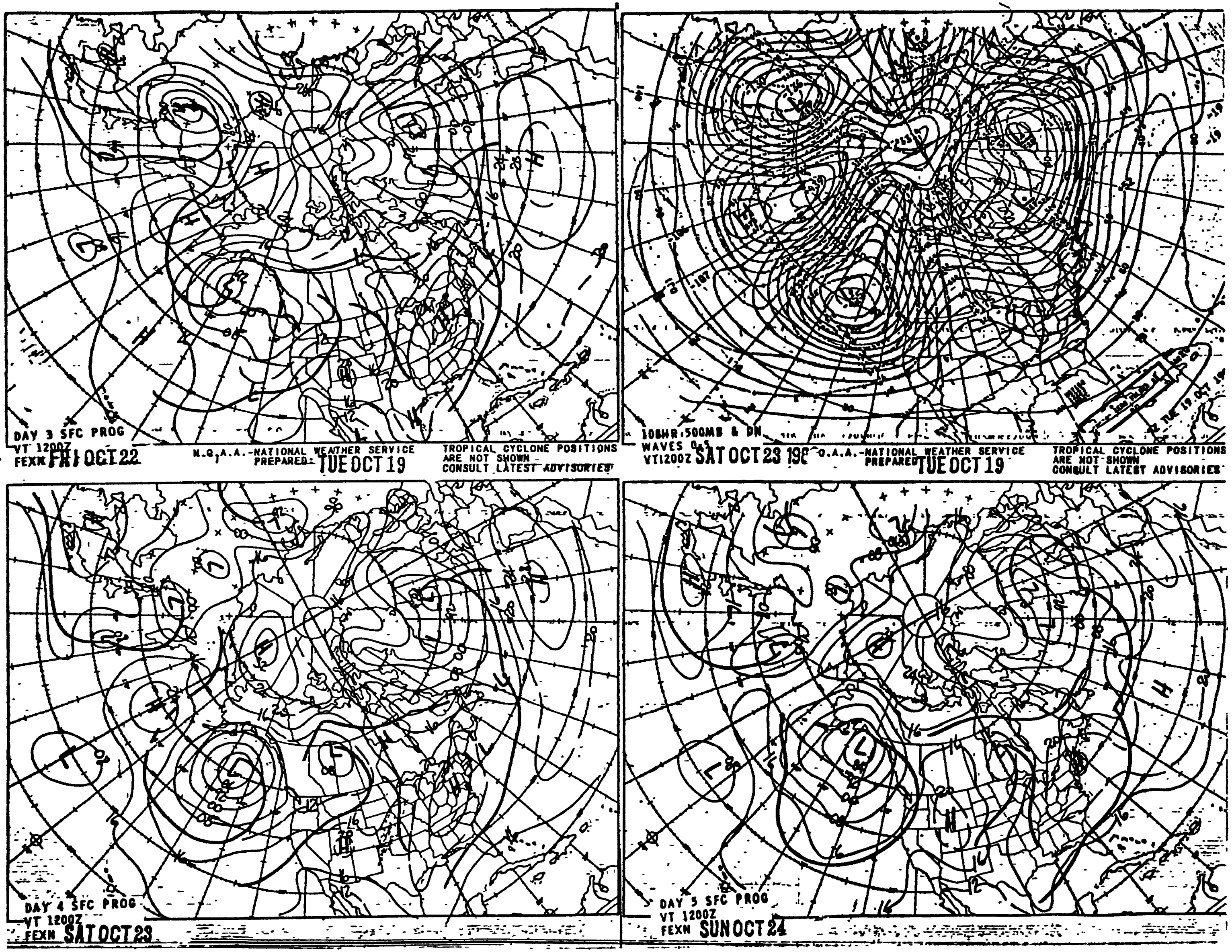


Figure 4-3-17.—Days 3, 4 and 5 Mid-range Surface/500-millibar Prognosis chart.

circles represent the major cities. Circles are open, one-quarter darkened, three-quarters darkened, or totally darkened, representing clear, scattered, broken, or overcast (total) cloud cover. A number appears below each station circle, representing the forecast flight-weather category (**1** for IFR, **2** for MVFR, and **3** for VFR conditions). The forecast surface winds are plotted as standard wind barbs on each station circle.

PROBABILITY OF PRECIPITATION AND PRECIPITATION TYPE FORECAST.—This chart has four panels that are valid 12, 24, 36, and 48 hours from the data base time. Each has isolines showing probability of precipitation from 05 percent to 95 percent. Symbols representing precipitation type are plotted over the major U.S. cities where the precipitation probability is equal to or greater than 25 percent. These symbols are : for rain, * for snow, and · for freezing rain.

Mid-range Surface Prognostic Chart

The mid-range surface forecast is produced once a day from the 1200Z data collection. This chart, shown in figure 4-3-17 has four panels. The first panel is valid at 1200Z of day 3 following the data collection. The second panel has the surface forecast for 1200Z on day 4. The next panel has a 500-millibar forecast for 1200Z on day 4, and the last panel has a surface forecast for 1200Z on day 5. Each surface forecast has isobars showing the pressure centers, and frontal positions. Using knowledge of the general weather to expect with different frontal systems and a station's climatology, a forecaster should have no problem making a 3- to 5-day outlook using this product. General wind directions and speeds may be forecast using the isobar orientation and spacing as a guide.

Mid-range Temperature Anomaly Forecast

Figure 4-3-18 shows an example of a temperature anomaly forecast. This product is received at most stateside NOCDs and Marine Corps Weather Detachments. Too often it is not understood and is discarded or ignored. It has three panels, for day 3, day 4, and day 5. Each panel has a diagram for the minimum temperature anomaly (MnTA), or difference from normal, and a second for the maximum temperature anomaly (MxTA). The MnTA usually is representative of the early-morning temperature, while the MxTA is representative of the afternoon temperature of the same day. Solid lines represent the anomaly or difference from the climatological mean maximum and mean minimum temperatures. These anomaly lines are drawn every 4 degrees Fahrenheit. The dotted lines represent 10 °F isotherms of the climatological temperatures. The MnTA diagram shows climatological minimum temperatures, while the MxTA diagram shows climatological maximum temperatures. These climatological backgrounds usually change every 2 weeks. Climatological background temperature periods used are valid from the 7th to the 21st of the month, and from the 22d of the month to the 6th of the next month.

To use this chart to obtain a temperature forecast for days 3 through 5, add the anomaly to the charted climatological temperature. You may also use your station's climatological temperature for greater accuracy. Use the monthly average maximum and minimum temperatures for forecasts valid for the middle-of-the-month period. Average the adjoining month's monthly maximum and minimum temperatures to get a set of maximum and minimum temperatures to use for the monthly transition periods.

For example, let's say that it is Monday afternoon, February 14, 1983. To find the forecast temperatures for Friday, February 18, 1983 (day 4, or the middle panel of figure 4-3-18) for Norfolk, Virginia, you would read the climatological base temperatures on the chart. You should read the temperature as 33 °F on the MnTA chart and 51 °F on the MxTA chart. Next, find the forecast anomalies. You should read +4 for the MnTA and +1 for the MxTA. These values indicate that the minimum temperature (T_{MIN}) will be 4 °F above normal and the maximum temperature (T_{MAX}) will be 1 °F above normal. Now add the anomalies to your climatological base temperatures. You will find a forecast T_{MIN} for Friday morning of 37 °F (33° + 4° = 37 °F). The forecast T_{MAX} for Friday afternoon would be 52 °F (51° + 1° = 52 °F).

You could use your station's climatological mean minimum and maximum temperatures instead of the charted temperatures. NAS Norfolk's mean maximum temperature is 51 °F, and the mean minimum is 32 °F. Adding the anomaly values to these temperatures would yield a more specific temperature forecast for Chambers Field.

If we were forecasting temperatures for the end-of-the-month period (22 February to 6 March) we would have to average the mean maximum and mean minimum temperatures for the two months to obtain a set of base temperatures. The mean temperatures for March are 41°F and 57°F. We would find 37°F [(41° + 32°)/2 = 37°F] for a mean minimum temperature and 54°F [(51° + 57°)/2 = 54°F] for a mean maximum temperature. Check the charted climatological base temperatures and determine if the end-of-the-month background change is actually done as anticipated. The anomalies are calculated using the background temperatures that appear on the chart, even though the change in the background temperatures may be done a few days early or late.

So far we have covered the most commonly used charts produced by the NWS's NMC. Several bulletins are routinely used that are in a more coded format for brevity of transmission. All bulletins are identified by a bulletin heading called a MANOP header. These were discussed in *AG3*, Appendix XI. Let's look at a few of the more frequently used coded bulletins to determine what information they contain.

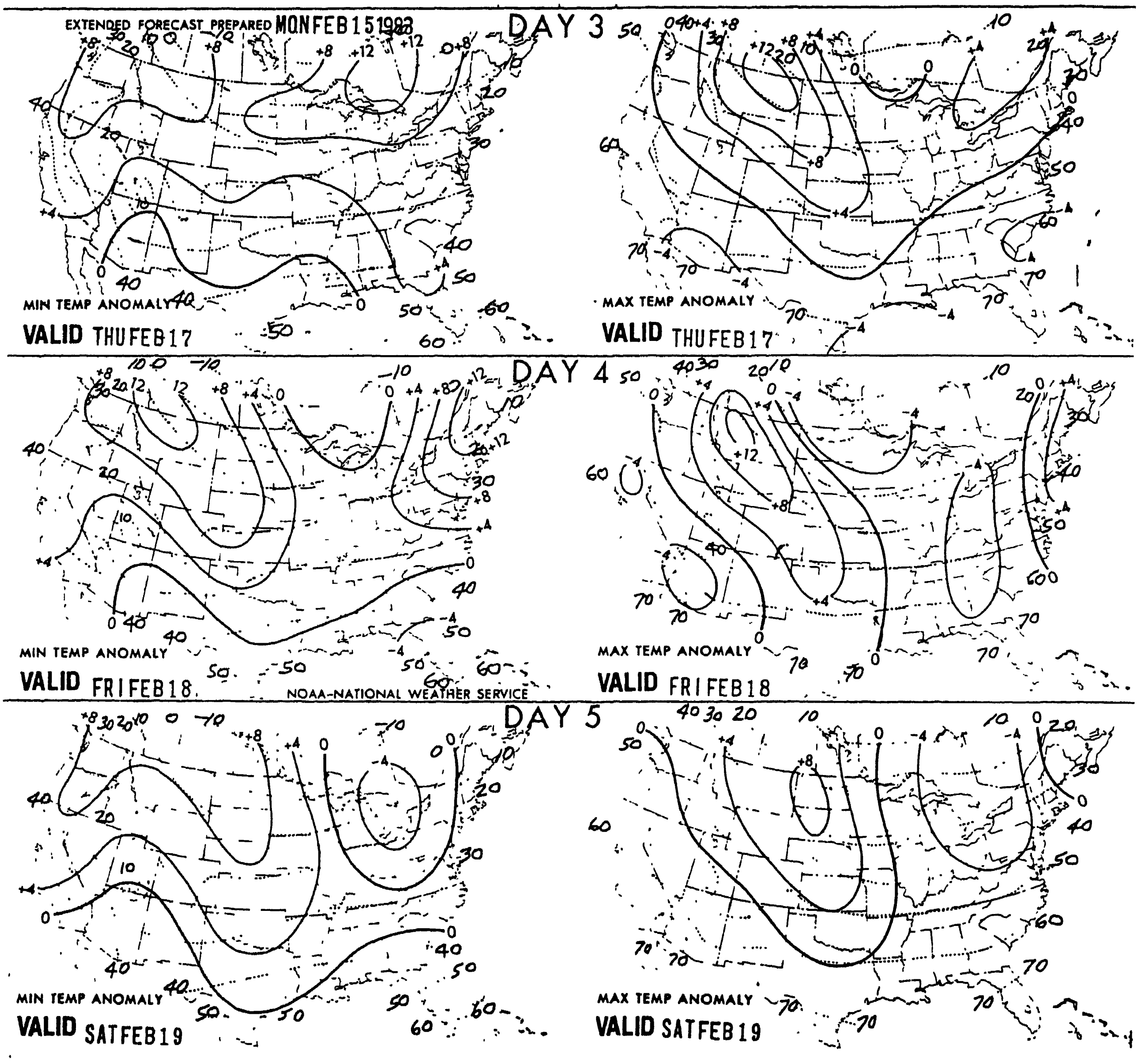


Figure 4-3-18.—Days 3, 4 and 5 Mid-range Temperature Anomaly Prognosis chart.

Learning Objective: Interpret commonly used National Weather Service bulletins.

FREQUENTLY USED NWS BULLETINS

Of the literally thousands of bulletins issued by the NWS, many are self explanatory—an information line adequately describes what information is presented. Many are observation reports, which are simply groups of coded observations. You have learned many of these observation reporting codes already. Others are forecasts or warnings in plain language. Many bulletins are so specialized that most Aerographers will have little need to know how to decipher them. Several frequently used bulletins, however, are coded and require a specific knowledge to use the data. Those are the bulletins we will cover in this section. They are the LFMII forecast output, the NGM forecast output, the MOS forecasts, and the trajectory forecasts.

LFMII Forecast Output

The LFM forecast output is available in bulletin format for many geographical regions. Most are identified by the MANOP *FOUSxx KWBC*, where the *xx* indicates the region. Each region generally contains six stations for which forecasts are produced. Table 4-3-4 lists the different regions and the forecast stations available.

Table 4-3-4.—LFM Forecast Data Regions and Stations Available With The MANOP FOUSxx KWBC, Where xx is the Region Number

XX	Stations Available					
60	BGR	CAR	CON	PWM	AFA	9B6
61	ALB	BTV	BOS	JFK	PHL	IPT
62	DCA	RDU	ILM	HAT	C7X	ORF
63	CAE	LAL	MIA	SAV	TLH	3J2
64	BUF	CRW	CLE	DAY	IND	PIT
65	ATL	TYS	MEM	BNA	STL	SDF
66	BHM	JAN	LIT	MOB	SHV	NEW
67	ORD	DET	INL	MKE	MSP	SSM
68	DSM	DDC	LBF	OMA	BFF	TOP
69	BRO	DFW	DRT	HOU	OKC	SAT
70	BIL	BIS	MSO	RAP	FSD	GTF
71	ABQ	CYS	DEN	ELP	LBB	PHX
72	BOI	MFR	PIH	SEA	GEG	PDX
73	CDC	FAT	LAX	RNO	SLC	SFO
74	YYB	YQB	YQW	YMW	YLH	YQT
75	YYC	YEG	YPA	YWG	YQD	YQR
76	YCG	YXS	YRV	MCD	XC	VR
77	G2GFA	G2GFB	G2GFC	G2GFD	G2GFE	G2GFF
78	X68	EDW	UCC	BTNM3	LG1N6	

Table 4-3-5 shows an example of the first block of data from a typical LFM forecast data bulletin. Each bulletin usually has five or six data blocks, one for each station. The second data block would appear just to the right of this data block so that two columns of station data are formed.

Let's break this example down to find what information is presented. The first line is the MANOP with the date-time group of the message. The second line identifies the message as LFM output from the 1200Z December 04, 1989 data base. The third line gives a data format, which we will discuss later. The fourth line lists the station identification for which the data is given in the first column (in this case *DCA* for Washington, D.C.), then continues with data analyzed at the data base time on the remainder of the line. The fifth through twelfth lines give the actual forecast data in 6-hour increments, and each begins with the number of hours from the analysis time that the forecast is valid. For instance, in the last line the first two digits are **48**. This means this line of data is the 48-hour forecast from 1200Z 4 December, valid at 1200Z 6 December.

As you can see, the data is arranged into columns. Each column has a header that identifies the data in that column. In the following explanation, we will use the seventh line of the bulletin, or the 18-hour forecast, as an example to further clarify each point. The column headers represent the following data:

- *RH* is the mean relative humidity in the lowest three layers of the LFM model (refer back to figure 4-3-1) or the surface-to-490-millibar level (about 19,000 feet MSL). In our example, the mean surface-to-19,000-foot relative humidity is **68** percent.

Table 4-3-5.—A Data Block From an LFM Forecast Bulletin With a MANOP Header and an Identification Line

FOUS62 KWBC 041200

OUTPUT FROM LFM 12Z DEC 04 89

STA	RH	R1R2R3	VVLI	HHDDFF	TBPSPTT
DCA	43	504440	///26	233229	6716///
06	45	524445	−0827	292512	6913000
12	62	394597	00424	352018	7306000
18	68	756599	01624	372514	7303003
24	58	527136	−0327	373116	6902000
30	48	596420	−1328	383117	6906000
36	55	514671	−1026	402910	7206000
42	54	434559	−0223	412516	7504000
48	42	346016	−1721	432718	7904000

- *R1* is the mean relative humidity in the boundary layer (the lowest LFM layer), which is from the surface to 50 millibars above the surface, or to about 1,400 feet AGL. In the example, this value is **75** percent.

- *R2* is the mean relative humidity in layer 2 of the LFM, from 50 millibars above the surface to about 720 millibars, or from about 1,400 feet AGL to about 9,000 feet AGL. You should read this value as **65** percent in our example.

- *R3* is the mean relative humidity in layer 3 of the LFM, from 720 millibars to 490 millibars, or about 9,000 feet AGL to 19,000 feet AGL. In our example, we should read the mean relative humidity as **99** percent. (This is the maximum humidity that the program calculates.)

- *VV* is the vertical velocity at 700 millibars, in microbars per second. In the 18-hour forecast, the value **016** means +16 microbars per second. Negative vertical velocities are preceded with a *minus* sign. A **−04** would mean −04 microbars per second, or that the air is sinking at 4 microbars per second.

- *LI* is the Lifted Index, in degrees Celsius. In our example **24** means 24 °C. Negative LI values are subtracted from 100. A **96**, for instance, would mean a lifted index of −04 °C.

- *HH* is the 1000-to-500-millibar-layer thickness, in decameters, with the hundreds value (usually a 5) omitted. In the example, the **37** means 537 decameters, or 5,370 meters.

- *DD* is the mean wind direction at the top of the boundary layer, or the approximate 1,400-foot wind direction, in hundreds and tens of degrees. In the example, the wind direction is forecast as 250°.

- *FF* is the mean wind speed at the top of the boundary layer, in whole knots. We should read **14** knots in our example.

- *TB* is the mean potential temperature through the boundary layer, in kelvin, with the hundreds units (usually a 2) omitted. In the example, our mean potential temperature through

the boundary layer is 273 K. Converting this temperature into degrees Celsius by subtracting 273 will yield the approximate temperature at 25 millibars above the surface.

- *PS* is the forecast sea level pressure, in tens and units of millibars. The **03** in our example means 1,003 millibars.

- *PTT* is the 6-hour accumulated precipitation for the period ending at the valid time of the forecast, in hundredths of an inch. This is a liquid equivalent in the case of snow. In the example, the **003** means 3 hundredths of an inch of precipitation has accumulated in the 6-hour period ending at 0600Z (18 hours after the analysis time of 1200Z).

Although the LFM data is expected to be available for a few more years, the NGM output, already available, was designed to replace the LFM output to obtain greater forecast accuracy.

NGM Forecast Output

The NGM forecast output bulletins are produced for groups of stations similar to the LFM forecast bulletins. However, the regional identification in the MANOP headers was changed. Table 4-3-6 lists the NGM forecast data regions, subregions, and stations available.

Table 4-3-6.—NGM Forecast Data Regions, Subregion Numbers, and Stations Available

			Eastern United States Region			
			FOUExx KWBC Stations Available			
60	BGR	CAR	CON	PWM	AFA	9B6
61	ALB	BOS	BTV	LGA	PHL	IPT
62	HAT	ORF	RDU	DCA	ILM	C7H
63	CAE	LAL	MIA	SAV	TLH	3H2
64	BUF	CRW	CLE	DAY	IND	PIT
66	BHM	JAN	LIT	MOB	SHV	MSY
			Middle United States Region			
			FOWMxx KWBC Stations Available			
65	ATL	TYS	MEM	BNA	STL	SDF
67	ORD	DTW	INL	MKE	MSP	SSM
68	DSM	DDC	LBF	OMA	BFF	TOP
69	BRO	DFW	DRT	HOU	OKC	SAT
70	BIL	BIS	GTF	MSO	RAP	FSD
71	ABQ	CYS	DEN	ELP	LBB	PHX
			Western United States Region			
			FOUWxx KWBC Stations Available			
72	BOI	MFR	PIH	PDX	SEA	GEG
73	CDC	FAT	LAX	RNO	SLC	SFO
			Alaskan Region			
			FOUSxx KWBC Stations Available			
86	EHM	CZF	TLJ	SVW	EDF	AKN
87	TNC	LUR	UTO	EIL	GAL	
			Canadian Region			
			FOCNxx KWBC Stations Available			
74	YQB	YLH	YYB	YMW	YOW	YQT
75	YWG	YYC	YPA	YQR	YQD	YEG
76	YCG	YXC	YXS	YVR	MCD	YVB

The arrangement of the data and the type of data, in some cases, is also slightly different from the LFM forecast bulletin. Table 4-3-7 is the first data block from a typical NGM forecast bulletin with the MANOP and identification lines.

A second station's block of data would be printed to the right of this data block, so the actual bulletin would be formatted in two columns of station data, similar to the LFM bulletin.

The MANOP and identification lines are similar to the LFM bulletin, which was described in the last section. Line 3 gives the coded format of the data columns, which is different from the LFM bulletin. Line 4, which begins with the three-letter station identifier, contains information from the analysis. Lines 5 through 12 are the forecast data. Each line begins with the number of hours after the analysis, in 6-hour increments, for which the forecast is valid, just as with the LFM format. In the following explanation, we will use line 7, the 18-hour forecast, as an example to clarify the breakdown of the information contained in the data columns and identified in line 3 by the coded format.

- *TT* is the time in hours from the analysis time that the forecast is valid. In line 7, the **18** is 18 hours after 1200Z 4 December, or 0600Z 5 December.

- *PTT* is the 6-hour accumulated precipitation (ending at the forecast time) in hundredths of an inch. In our example, **000** means no precipitation is forecast. An entry of **105** would indicate 1.05 inches of rain should fall in the 6-hour period ending at 0600Z.

Table 4-3-7.—A Data Block From a Typical NGM Forecast Bulletin With MANOP and Identification Lines

FOUE62 KWBC 041200			
OUTPUT FROM	NGM 12Z DEC 04 89		
TTPTTR1R2R3	VVVLI	PSDDFF	HHT1T3T5
DCA//383913	−3027	173026	22918686
06000475533	−1126	152709	30968990
12000477354	02215	112218	34999593
18000637223	00915	072520	34989595
24000836511	−1512	062819	35979697
30000694355	−1610	072812	40029600
36000666631	01910	052817	42039801
42000767451	00711	052616	43020299
48000965517	00108	032719	45010499

- *R1* is the mean relative humidity in the lowest level of the NGM model—the boundary layer. Since the top of the boundary layer is 35 millibars above the surface, this value is the relative humidity in the layer from the surface to roughly 1,000 feet AGL. In our example, **63** is 63 percent relative humidity.

- *R2* is the mean relative humidity in layers 2 through 9 of the NGM model. This equates to the layer from the boundary layer up to 480 millibars, or roughly 19,000 feet AGL. Example: **72** means the relative humidity in layers 2 through 9 is 72 percent.

- *R3* is the mean relative humidity in layers 10 through 13 of the NGM model. This equates to the 480-millibar level through the 180-millibar level, or roughly 19,000 feet to 41,000 feet. Example: **23** is 23 percent.

- *VVV* is the instantaneous vertical velocity in microbars per second at the 700-millibar level. Negative vertical velocities, or movement of air downward, are prefixed with a minus sign. Example: **009** in this case is 9 microbars per second (upward) vertical velocity.

- *LI* is the Lifted Index in degrees Celsius. Negative LI values are subtracted from 100. Example: **15** is 15 °C, but a **95** would mean the Lifted Index is −05 °C.

- *PS* is the sea level pressure in tens and units of millibars. Example: **07** is 1,007 millibars.

- *DD* is the wind direction in hundreds and tens of degrees at the boundary level, or about 986 feet above the surface. Example: **25** means the wind is from 250° true.

- *FF* is the wind speed in knots at the boundary level, or about 986 feet above the surface. Example: **20** means the wind speed is 20 knots.

- *HH* is the 1,000-to-500-millibar thickness in tens and units of decameters. The hundreds digit (5) is omitted. Example: **34** means the 1000/500 mb thickness is 534 decameters, or 5,340 meters.

- *T1* is the mean temperature in degrees Celsius through the boundary layer. In practice, this may be used as the forecast temperature for 17 millibars (roughly 480 feet) above the surface, which is usually rounded off to 500 feet AGL. Temperatures cooler than 0 °C are subtracted

from 100. Example: **98** means that the 500 foot temperature is −2 °C.

- *T3* is the mean temperature through layer 3 of the NGM model in degrees Celsius. This layer extends from 78 to 138 millibars above the surface, or roughly from 2,240 feet to 3,925 feet AGL. In practice, this is used as an approximate temperature for the 3,000-foot AGL level. Temperatures below freezing are subtracted from 100. Example: **95** means the 3,000-foot temperature is −5 °C.

- *T5* is the mean temperature in degrees Celsius through layer 5 of the NGM, which extends from about 194 to 255 millibars above the surface, or essentially from about 5,836 to 7,906 feet AGL. In practice, the mean temperature of layer 5 (T5) is used as the temperature at 7,000 feet AGL. Temperatures below freezing are subtracted from 100. **95** means the 7,000 foot temperature is −5 °C.

MOS Bulletins

Most forecasters know that while the LFM and the NGM forecast data bulletins are very helpful aids in producing a forecast for their station, they do not contain all of the necessary information. Therefore, LFM Model Output Statistics (MOS) bulletins, which compare the current synoptic situation with the climatological records and past weather occurrences, should also be used. Probability forecasts for many stations are available in the MOS bulletins. Table 4-3-8 lists the available MOS bulletins by region.

Table 4-3-8.—MOS Forecast Regions, Subregions, and Stations Available

				FOUSx KNKA - United States						
X	**STATIONS AVAILABLE**									
1	AUS	DFW	DRT	IAH	SAT	SHV				
2	ABI	ABQ	BTR	LCH	LBB	MAF	OKC	ICT	SPS	
3	BOI	CYS	GGW	GTF	MOT	SEA	GEG			
4	DAG	LAS	OAR	OAK	PHX	SAC	SLC	SAN	SMX	TUS
5	ESF	ATL	MCN	MIA	MGM	RDU	SAV	TPA		
6	ACY	BOS	BTV	CAR	CHS	CAE	ISP	JAX	JFK	ORF
	PHL	RIC	DCA	BWI						
7	CMH	DAY	DTW	FWA	SSM	STL	SDF			
8	COS	DEN	DUL	MCI	LSE	LIT	MEM	OMA	RAP	
				FOUExx KWBC - Eastern United States						
XX	**STATIONS AVAILABLE**									
Ø1	FTK	GUS	LCK	MTC	FFO	OSC				
Ø2	BRN	ATZ								
Ø3	VPS	LSF	OZR	HRT	MXF	VAD				
Ø4	PAM									
Ø5	DAA	FAF	TYS	LFI	RIC	GSB				
Ø6	TØ1	2DP								
Ø7	AGR	SVN	JAX	MCF	COF	WRB				
Ø8	HST	EYW	TØ4							
Ø9	CHS	CAE	MGE	MMT	MYR	POB	SSC			
1Ø	TØ3	2PJ	DP1							
11	ADW	MTN	DVD	FME						
12	BUF	GTB	RME	FMH	SYR	CEF				
13	BGR	BTV	AYE	LIZ	PSM	PBG				
14	BOS									
15	ACY	DOV	MUI	WRI	PIT					

Table 4-3-9.—An Example of a Typical Section of a MOS Bulletin With the Data Format for a Single Station

FOUS25 KWBC 041200

HDNG FOUS25 LFM-MOS GUIDANCE 12/04/89 1200 GMT

DY/HR	04/18	05/00	05/06	05/12	05/18	06/00	06/06	06/12	00
NPA									
POP06		2	2	5	5	5	0	2	
POP12				5		10		2	10
QPF06		000/1	000/1	000/1	000/1	000/1			
QPF12				0000/1		0000/1		0000/1	
TSTM				0		1		6	
POPT	1236/3	0902/3	0200/3	0300/3	0100/3	0100/3	0100/3	0000/3	
POSA			9999/9999/9999/0						
MN/MX				37		66		47	68
TEMP	51 54	45 40	40 41	40 55	64 64	57 53	51 51	51 58	
DEWPT	27 28	28 29	32 34	34 46	47 48	46 45	44 44	44 50	
WIND	2906	2307	2811	2904	2510	2606	2905	0306	
CLDS	4321/2	4222/2	5211/1	4322/2	3421/2	4322/2	4212/2	3223/3	
CIG	000009	000009	000019	110018	000117	000117	001117	011116	
VIS	000009	000009	000008	101117	000010	000019	000018	101116	
C/V	6/6	6/6	6/6	6/6	6/6	6/6	6/6	6/6	
OBVIS	91X0/1	90X0/1	80X2/1	70X3/1	91X1/1	90X1/1	80X2/1	60X4/1	

Line 1 is the MANOP header. Line 2 is the product identification, or heading line, which contains the date and time in GMT of the data cycle the product was produced from. Line 3, which begins with *DY/HR*, contains the forecast date (*DY*) and time (*HR*) in GMT that each forecast column is valid. These three lines appear only at the beginning of each bulletin.

Each station's data begins with a line containing only that station's three-letter identifier. This is line 4. In our example, the station is *NPA*, for NAS Pensacola, Florida. Lines 5 through 20 contain the actual forecast data. We will use the **06/00** forecast, or the forecast for 0000Z 6 December 1989, as our examples to clarify each point:

- *POP06* is the probability of precipitation during the 6-hour period ending at the forecast time. In our example, **5** is 5 percent chance of precipitation.

● *POP12* is the probability of precipitation during the 12-hour period ending at the forecast time. Probabilities are to the nearest percent. **10** is a 10 percent chance of precipitation.

● *QPF06* is the Quantitative Precipitation Forecast probability for the 6-hour period ending at the forecast time. More simply, this is a probability of the total accumulated precipitation during the period falling into the ranges listed below. All probabilities are in tens of percent. (A 7 would mean 70 percent.) The format is *ABC/D*. *A* is the probability of receiving at least 0.25 inch but less than 0.50 inch of precipitation. *B* is the probability of receiving at least 0.50 inch but less than 1.00 inch. *C* is the probability of receiving 1.00 inch or more. *D* is the MOS categorical forecast (pick of the category with the most likely occurrence), where the categories are **1**, less than 0.25 inch; **2**, *A*; **3**, *B*; and **4**, *C*. In our example, **000/1** means that we have 00 percent chance of receiving total rainfall accumulation during the period in category *A*, *B*, or *C* and that if any precipitation is received, it will total less than 0.25 inch (category 1).

● *QPF12* is the Qualitative Precipitation Forecast for the 12-hour period ending at the forecast time. Again, probabilities are in tens of percent. The format is *ABCD/E*. *A*, *B*, and *C* are the same as the QPF06 *A*, *B*, and *C* categories. *D* is the probability of receiving 2.00 inches or more of precipitation during the 12-hour period. *E* is the MOS pick of the most likely category: **1**, **2**, and **3** are the same as in the QPF06 forecast; **4** is 1.00 to 1.99 inches; and **5** is 2.00 inches or more. **0000/1** means that we have a 00 percent chance of receiving total rainfall accumulations in categories *A*, *B*, *C*, or *D* and that if any precipitation is recieved, it will total less than 0.25 inch.

● *TSTM* is the probability of receiving a radar echo from a precipitation area of level 3 (VIP 3) or stronger (which would imply thunderstorm activity) from within the station's 20-mile-square radar coverage reporting block (MDR block), during the 12-hour period ending at the forecast time. Basically, this is the probability of having a thunderstorm within 10 miles of your station. Probabilities are to the nearest percent. **1** means there is a 1 percent chance of having a thunderstorm within 10 miles of the station between 1200Z 5 December and 0000Z 6 December.

● *POPT* is the probability of precipitation type. All probabilities are to the nearest percent. The format is *AABB/C*. *AA* is the probability of freezing rain. *BB* is the probability of snow or sleet. *C* is the MOS categorical forecast 1, 2, 3, or 4, where **1** is freezing rain, **2** is snow or sleet, **3** is rain or mixed, and **4** is undetermined. **0100/3** means that we have a 1 percent chance of freezing rain but that the best category is **3**, rain or mixed precipitation.

● *POSA* is the probability of snow amount for the 12-hour period ending at the 24-hour forecast time. The entire string of 13 digits and 3 solidi are for the single 12-hour period. All 9's indicate no snow is forecast. The forecast uses two different types of probabilities and is presented in the format *AABB/CCDD/EEFF/G*.

CONDITIONAL PROBABILITY	UNCONDITIONAL PROBABILITY
AA for $\geq$2 inches of snow if it snows.	*BB* for $\geq$2 inches of snow.
CC for $\geq$4 inches of snow if it snows.	*DD* for $\geq$4 inches of snow.
EE for $\geq$6 inches of snow if it snows.	*FF* for $\geq$6 inches of snow.

G is the MOS categorical forecast for snow amount. The four categories are **0**, **2**, **4**, and **6**, where **0** is <1 inch, **2** is 2 to 3 inches, **4** is 4 to 5 inches, and **6** is >6 inches.

The example **9999/9999/9999/0** indicates that no snow is forecast. If the POSA were **0902/0300/0000/0**, it would mean a 9% chance of $\geq$2 inches and a 3% of $\geq$4 inches of snow between 05/0000Z and 05/1200Z if it snows, but only a 2% chance of any snow. MOS forecasts **0**, less than 1 inch of snow.

● *MN/MX* is the minimum or maximum temperature forecast, in degrees Fahrenheit, that may occur at any time during the 12-hour period ending at the forecast time. **66 °F** is the maximum temperature forecast between 05/1200Z and 06/0000Z.

● *TEMP* is the actual temperature forecast, in degrees Fahrenheit, in 3-hour increments; the first temperature is for the forecast time, while the second is 3 hours later. **57 53** in the 06/00 column means the forecast temperature at 06/0000Z is 57 °F, while the temperature 3 hours later, at 06/0300Z, should be 53 °F.

● *DEWPT* is the dew-point temperature forecast in 3-hour increments (same as the temperature). **46 45** means the dew point at 06/0000Z is 46 °F, while the dew point temperature 3 hours later should be 45 °F.

● *WIND* is the surface wind forecast at the forecast time in the format *DDFF. DD* is the wind direction, in tens of degrees, and *FF* is the wind speed, in whole knots. **2606** means the wind will be from 260° true at 06 knots at 06/0000Z.

● *CLDS* is the forecast for the total cloud amount probability at the forecast time. These probabilities are in tens of percent, and are presented in the format *ABCD/E. A* is the probability of clear skies. *B* is the probability of scattered cloud cover. *C* is the probability of broken cloud cover. *D* is the probability of overcast cloud cover. *E* is the MOS categorical forecast 1, 2, 3, or 4, where **1** is clear skies (0/10 coverage); **2** is scattered clouds (1/10 to 5/10 coverage); **3** is broken clouds (6/10 to 9/10 coverage); and **4** is overcast clouds (10/10 coverage). **4322/2** means a 40% chance of clear skies, 30% chance of scattered cloud cover, and 20% chances of broken or overcast conditions; MOS forecasts **2**, scattered clouds at 06/0000Z.

● *CIG* is the ceiling height probability forecast at the forecast time. Probabilities are in tens of percent and in the format *ABCDEF. A* is the probability of a ceiling <200 feet. *B* is the probability of a ceiling of 200 to 400 feet. *C* is the probability of a ceiling of 500 to 900 feet. *D* is the probability of a ceiling of 1,000 to 2,900 feet. *E* is the probability of a ceiling of 3,000 to 7,500 feet. *F* is the probability of a ceiling greater than 7,500 feet. **000117** means 0% chances of a <200-foot, a 200- to 400-foot, or a 500- to 900-foot ceiling, a 10% chance of 1,000- to 2,900-foot or a 3,000- to 7,500-foot ceiling, and a 70% chance of a >7,500-foot ceiling.

● *VIS* is the probability forecast of a range of visibilities in statute miles at the forecast time. Probabilities are in tens of percent and are in the format *ABCDEF. A* is the probability of <1/2-mile visibility. *B* is the probability of 1/2- to 7/8-mile visibility. *C* is the probability of 1- to 2 3/4-mile visibility. *D* is the probability of 3- to 4-mile visibility. *E* is the probability of 5- to 6-mile visibility. *F* is the probability of >6-mile visibility. **000019** in the 06/00 forecast column means a 0% chance of <1/2-mile, 1/2- to 7/8-mile, 1- to 2 3/4-mile, or a 3- to 4-mile visibility, a 10% chance of a 5- to 6-mile visibility, and a 90% chance of >6-mile visibility.

● *C/V* is the MOS categorical forecast for ceiling height (*C*) and visibility (*V*). Forecasts are given as a number from 1 to 6 in each category. The number **1** is *A;* **2** is *B;* **3** is *C;* **4** is *D;* **5** is *E;* and **6** is *F* in their respective groups given above. **6/6** means MOS forecasts the ceiling to be >7,500 feet and the visibility to be >6 miles at the forecast time.

● *OBVIS* is the probability of obstructions to vision, in tens of percent, in the format *ABCD/E. A* is the probability of no obstruction. *B* is the probability of haze or smoke. *C* is the probability of blowing sand or snow. *D* is the probability of fog or ground fog. *E* is the MOS categorical forecast; **1** is *A;* **2** is *B;* **3** is *C*; and **4** is *D.* **90X1/1** means a 90% chance of no obstruction, 0% chance of haze or smoke, no forecast for high winds, and a 10% chance of fog. The MOS forecasts **1**—no obstructions to vision.

NGM MOS Forecast Bulletins

The NGM MOS guidance bulletins, or the NGM Perfect Prog Forecasts, were first issued shortly after the April 1987 *Technical Procedure Bulletin 369* announced the implementation of that product. As of December 1989, only limited data is available on the NGM MOS bulletins. In addition to the MANOP, product identification, and forecast valid time line, the NGM MOS has 4 data lines. The first contains only the station's three-letter identifier. The second is a *POP/MN-MX* line with forecasts of 12-hour probability of precipitation forecasts followed by a forecast maximum or minimum temperature. The third line is a *WIND* forecast identical to the LFM MOS wind forecast, and the last line is a *CLDS* forecast identical to the LFM MOS forecast. These bulletins are available under the MANOP series beginning with *FOUS14 KWBC*, in alphabetical station identifier order.

You may expect that the NGM MOS bulletins soon will be expanded to include all of the information available in the LFM MOS bulletins and that they will be available for all stations currently covered by the LFM MOS. The complete format should be very similar to the LFM MOS as well. At present, in situations when the NGM charts and forecast guidance are followed, the NGM MOS bulletins should serve

as the primary forecasting aid for the information that is covered.

Trajectory Bulletins

The trajectory bulletins provide 24-hour forecasts for parcels of air in the lower atmosphere. The objective of these forecasts is to provide greater accuracy and detail in the forecasting of moisture distributions below 700 millibars. These forecasts trace the paths of parcels of air that are expected to end up over the forecast station at the 24-hour forecast time.

Table 4-3-10 shows a typical trajectory bulletin forecast for a single station. The first and second lines in the bulletin provide the MANOP header and product identification, as well as the date-time group. The third line in the bulletin gives the forecast times, with the first time being the actual analysis time. The fourth line is the headers for each block of data. The fifth line contains the station identifier and the 700-millibar data, while the sixth line contains the 850-millibar data. The last line provides surface information. The data represented in the columns are the following. The examples given are for the 700-millibar line, under the 030000Z analysis data column.

- *LAT* is the north latitude of the parcel of air at the specified time, to the nearest tenth of a degree. In our example, the parcel of air forecast to be over Miami at 040000Z was at **207**, or 20.7 °N latitude at the 030000Z analysis time.

- *LON* is the west longitude, to the nearest tenth of a degree, of the parcel of air at the time specified. The hundreds unit is dropped for longitudes greater than 100. The 700-millibar air parcel over Miami at the 040000Z forecast was at **836**, or 83.6 °W longitude at the 030 analysis time.

- *PPP* is the parcel's pressure, in milli at the time specified. The thousands ui dropped for pressures over 1,000 millibars. parcel of air at 700 millibars over Miami a 040000Z forecast time was at **702**, or 702 mill at the 030000Z analysis time.

This same data format is followed for all levels for the analysis time, as well as for tl 12-, and 18-hour forecast times. The data i 24-hour forecast column is different. The eler presented in that column are the *MTP, TE DEWPT*, and *K*.

- *MTP* is the model terrain pressure, c forecast surface pressure (station pressure) a station for the forecast time (040000Z). **008** n the forecast station pressure will be millibars.

- *TEMP* is the temperature of the air p in degrees Celsius at the forecast time. **7.6** n the 700-millibar temperature will be 7.6 °C a forecast time.

- *DEWPT* is the dew-point temperatu the parcel of air in degrees Celsius at the for time. **−5.3** means the dew-point temperatu 700 millibars will be −5.3 °C at the forecast t

- *K* is the forecast K-Index. (See Ur Lesson 2.)

Following the trajectory paths not only allow you to see where the air over your st

Table 4-3-10.—An Example of a Typical Station's Data From a Trajectory Bulletin

FOUS57 KWBC 030000

TRAJECTORY GUIDANCE 12/03/89 0000 GMT

		030000Z	030600Z	031200Z	031800Z	040000Z		
		LATLONPPP	LATLONPPP	LATLONPPP	LATLONPPP	MTP	TEMP	DEWPT
MIA	700	207836702	216837724	229833729	243822717		7.6	−5.3
	850	208812857	217820868	228822872	244818863		15.7	9.4
	SFC	220790980	226795993	231800003	242804007	008	25.7	21.4

at the forecast time originated, but it will allow you to determine vertical velocities. For instance, the 700-millibar parcel originated at 702 millibars at 030000Z, and 6 hours later will have a pressure of 724 millibars. This implies a net downward vertical motion of 22 millibars per 6 hours.

Some of the best uses of trajectory data is to forecast the changes on a *Skew T, Log P Diagram*, or to forecast necessary input parameters for *Refractivity* forecast calculations. Use table 4-3-11 to find the proper bulletin MANOP for your location.

SUMMARY

In this lesson we have discussed some of the charts and products used daily by Navy Aerographer's Mates. We have addressed the minimum knowledge you must have in order to perform your day-to-day duties. You can acquire additional information by reading or reviewing some of the sources cited in this lesson. In time, through the continued use of the charts and products we have discussed, you will acquire the skill to "read" the charts and products as easily as you read a book. This skill can only be obtained through practice. As an exercise, in your weather briefing area, have your Chief, LPO, or Section Leader help you to locate some of the charts and products we have discussed. Interpret as much information as you can from each of the charts or bulletins. Your Chief or LPO will assist you with any difficulties in interpretation. Discuss your interpretation with them to ensure you are interpreting the information correctly.

Table 4-3-11.—Trajectory Bulletin Regions and Available Stations With the MANOP FOUSxx KWBC

XX	Stations Available									
50	BOI	MFR	PDX	SFO	SEA	YKM	GEG	GTF		
51	BIL	BIS	DEN	DSM	INL	LND	MSP	LBF	RAP	
52	GRB	PIA	SSM	FNT	IND	LOU	CLE	CRW	PIT	
53	ALB	BOS	BUF	BTV	CAR	LGA	PWM	DCA	IPT	
54	DEN	LAX	MFR	PHX	PIH	RNO	SLC	SAN	SFO	UCC
55	SAT	ALS	BRO	DDC	ELP	FTW	LBB	OKC		
56	BHM	HOU	JAN	LIT	MEM	UMN	MSY	STL	TOP	
57	ATL	CAE	GSO	TYS	LAL	MIA	TLH	ILM		

UNIT 4—LESSON 4

THE TERMINAL AERODROME FORECAST (TAF) CODE

OVERVIEW	OUTLINE
Identify the reference that contains basic guidance for the Terminal Aerodrome Forecast (TAF) code.	Basic guidance
List five basic guidelines for composing a terminal aerodrome forecast.	Guidelines for composing a terminal aerodrome forecast
Identify the code groups used in the Terminal Aerodrome Forecast (TAF) code.	The TAF code format
Identify the types of remarks that may be used within a TAF.	Remarks
Identify the different change groups and state when these groups should be used in the TAF.	Change groups

THE TERMINAL AERODROME FORECAST (TAF) CODE

On March 1, 1986, the Navy and Marine Corps stopped using the Plain Language Terminal Area Forecast (PLTAF) and started using the Terminal Aerodrome Forecast (TAF) code for all stateside and overseas locations. This code was already in use by the USAF Air Weather Service personnel and at certain overseas Naval Oceanography Command detachments.

In this lesson, we discuss some basic background information about Terminal Aerodrome Forecasts as well as how to encode and decode the TAF code.

Learning Objective: Identify the reference that contains basic guidance for the TAF code.

BASIC GUIDANCE

The basic guidance for use of the TAF code is provided in Naval Oceanography Command instruction (NAVOCEANCOMINST) 3143.1, *Terminal Aerodrome Forecast (TAF) Code*; NAVAIR 50-1P-11, *International Meteorological Codes*; AWSR 105-2, *Weather Communications Policy and Procedures*; AWSR 105-24, *Meteorological Codes*; and AWSR 105-27, *Terminal Aerodrome Forecast (TAF)*.

The TAF code is used by the forecasters and briefers to provide information about expected weather conditions that will occur at or near an airfield (in the airfield's control zone as defined by the base operations manual) to other users. It may also be used in-house for briefing purposes.

Learning Objective: List five basic guidelines for composing a terminal aerodrome forecast.

GUIDELINES FOR COMPOSING A TERMINAL AERODROME FORECAST

Before we cover the specifics of the code, I want to stress five important rules that you, as

the forecaster or briefer, should keep in mind when composing a terminal aerodrome forecast: your forecast should be complete; it should be accurate; it should be specific; it should be on time; and it should be written to cover weather occurrences, not to cover the check blocks on a forecast verification sheet. There are many users who rely on the information contained in the TAF code to make significant judgments and operational decisions. Pilots will either fly or stay grounded based on your forecast. Event planning for the next 24 hours may hinge on your forecast. Many man-hours and Government dollars will be spent either economically or wastefully based on your forecast. Because of this, it is essential that you remember these basic guidelines when writing your forecast.

- Be complete! Adequately describe all weather events that you feel will occur in the entire 24-hour period covered by your forecast. The TAF is given wide distribution through both local and limited worldwide electronic dissemination. While the local pilots may find it convenient to pick up the phone and get an update every hour or so, this isn't as easy for the pilot inbound to your station from overseas or for the pilot flying an 18-hour round-robin mission without intermediate stops. When you are writing a TAF, say the 0900Z forecast (which will be valid until 0900Z the following morning), write it as if you know that the person receiving it will not be able to receive an update and will be flying on your forecast at 0830Z the following morning. If you feel fog will develop at 0845Z, include it in the forecast. Do not ignore it just because it's near the end of the forecast period. One of the biggest problems we have seen with TAFs (and PLTAFs) is that some forecasters actually write only a 6-hour forecast and assume that the next forecast issued 6 hours later will take care of anyone who will be flying later during the day.

- Be accurate! The forecaster must insure that all available information has been used and properly interpreted when the forecast is made. The forecaster, or the briefer, must also insure that all elements of the forecast are accurately encoded. Proofread the TAF before you transmit. It is just as important to continuously monitor the developing weather conditions so that amendments to the TAF may be issued if necessary.

- Be specific! Specify the approximate time any significant changes are expected to begin and end. To say that the prevailing conditions over a 24-hour period will be VFR, with an intermittent IFR condition covering the entire forecast period, is simply an admission by the forecaster that the forecaster really doesn't have the slightest idea what will happen. If, for example, you are writing a forecast for the Tropics and expect fine flying weather except in isolated afternoon or evening rain showers, nail down the time when rain showers will occur within a specific time window. Do not get overly specific, however. Base your change groups only on significant changes in the forecast. The cloud ceiling changing from 12,000 feet to 10,000 feet usually isn't significant. A ceiling changing from MVFR to IFR would be very significant. Some forecasters routinely use change groups at constant times or time intervals, such as at 1500Z forecast with change groups at 1800Z, 0000Z, 0600Z, and 1200Z. These TAFs should be carefully scrutinized prior to use, since it is highly unlikely that the weather conditions will actually change at specified intervals.

- Be on time! Start writing the forecast early enough so that it may be encoded and transmitted by the proper file time. All TAFs will have a valid period of 24 hours and will be filed at 6-hour intervals with file times at 0300Z, 0900Z, 1500Z, and 2100Z. If your data transmission terminal is not operational and your file time is approaching, investigate alternative means to transmit your TAF. This may be as simple as calling another NOC Detachment/Facility/Center and dictating your TAF over the phone so that they may transmit it for you.

- Write to cover weather occurrences, not the blocks on a verification sheet! While forecast verification programs are helpful in a forecast improvement or a training program, occasionally people place more importance on writing a forecast that will be easier to verify than on writing an accurate forecast. If you concentrate on writing a complete, specific, and accurate forecast, and are doing a good job at it but still receive low verification scores, then talk to your LPO. The problem may not lie with your forecasts, but with the verification criteria. Remember, the primary goal of forecasting is Flying Safety.

Learning Objective: Identify the code groups used in the Terminal Aerodrome Forecast (TAF) code.

THE TAF CODE FORMAT

The TAF code format used by the Navy, Marine Corps, and Air Force (the Air Force forecasts for the Army) is the World Meteorological Organization (WMO) code *FM51-V TAF - Aerodrome Forecast*, with some minor regional modifications as permitted by the WMO[1]. The following TAF format is the U.S. Military version currently in use:

TAF CCCC (*or* CCC) $G_1G_1G_2G_2$ (COR/AMD/RTD) dddff/f_mf_m VVVV w'w' $N_SCCh_Sh_Sh_S$ $\emptyset G_FG_FT_FT_F$ $6I_Ch_ih_ih_it_L$ $5Bh_Bh_Bh_Bt_L$ $QNHP_2P_2P_2P_2INS$ (Remarks) TTTTT GGG_eG_e *(or* GG) AMD/COR GGgg

The meaning of each group is explained in the following sections.

The Message Heading

TAF CCCC (or *CCC)* $G_1G_1G_2G_2$ and, if required *COR* and/or *AMD* is the Message Heading.

TAF is the message identifier and is always sent as the first group when you are transmitting a TAF. This identifier is deleted from individual reports when they are retransmitted in a group (collective), because it will be placed at the beginning of the message containing the group of reports.

- *CCCC* or *CCC* is the station identifier, a three- or four-letter or letter/numeral combination. Nearly all stations within the continental U.S. use the *CCC*, a three-letter/numeral combination as assigned by the U.S. Federal Aviation Administration (FAA), while overseas units, including those in Alaska and Hawaii, use the four-letter ICAO identifier in the *CCCC* format[2]. U.S. naval ships normally use their four-letter International Radio Call Sign (IRCS) for *CCCC*. IRCSs may be decoded using *Call Sign Book For Ships*, ACP-113.

- $G_1G_1G_2G_2$ is the valid period of the forecast. G_1G_1 is the time, in whole hours UTC, of the beginning of the 24-hour valid period of the forecast, or in the case of an amendment, correction, or retarded forecast, the time, to the nearest whole hour, that the change is sent. G_2G_2 is the time, in whole hours UTC, of the end of the forecast period.

- *COR* is encoded following the valid period of the forecast when any element of the forecast has been corrected. A correction is sent only when the TAF has already been transmitted and it is discovered that some element has been encoded incorrectly or was omitted from the TAF. When a *COR* is transmitted, the G_1G_1 should be altered to reflect the time in whole hours UTC nearest the transmission time. For example, if a correction of the 1515 Pensacola TAF is transmitted at 1530, the header would read *TAF NPA 1615 COR*. When a correction is transmitted, a *COR GGgg* group must also be added as the last group in the message. The *GGgg* reflects the time that the correction was issued (first disseminated via any means) in whole hours (*GG*) and minutes (*gg*) UTC.

- *AMD* will follow the valid period when the forecaster issues an amendment to the forecast. An amendment means that the forecaster has re-evaluated the data and decided to change any element or add a group. When an amendment is issued, the G_1G_1 in the valid period group must also be changed to reflect the nearest whole hour to the time the amendment is transmitted. The header for an amendment to Pensacola's 1515 TAF transmitted at 1529 UTC would read *TAF NPA 1515 AMD*. Amendment also requires that an additional group be added as the last group of the message. In this case the group would read *AMD GGgg*, where *GGgg* is the time in hours and minutes UTC that the amendment is issued.

[1]A major change is currently in the planning stage for WMO code *FM15-V MATAR* and code *FM16-V SPECI*, which may overlap and effect *FM51-V TAF*. These changes are anticipated to become effective in November 1992, but some sources think this is optimistic and that the change will not be implemented until sometime in 1993 or 1994.

[2]One of the proposed changes in WMO code FM15-V and FM16-V requires all stations to identify their observations with a four-letter identifier. U.S. stations using a combined letter/numeral (alphanumeric) identifier will have to be reassigned a new identifier. These four-letter identifiers will most likely be used to identify TAFs, as well as observations.

An amended TAF should be issued anytime the forecaster considers it advisable in the interest of flying safety or for the efficiency of aircraft operations, flight planning, operational control, and in-flight assistance to aircraft. The forecaster has both the authority and the responsibility to issue amendments, and must determine when amendments should be issued. The forecaster should consider the following guidelines as the minimum criteria for issuing an amendment. These criteria are based on NATOPS requirements and regulations:

1. When ceilings and/or visabilities are observed or are later forecast to increase to, exceed, or decrease to less than any of the following values, an amendment should be issued:

Ceiling	Visibility
3,000 feet	3 statute miles (4,800 meters)
1,000 feet	1 statute mile (1,600 meters)
200 feet	1/2 statute mile (800 meters)

2. When expected or actual wind speeds change by 10 knots or more from the forecast speed or when the wind direction changes or is expected to change by 30 degrees or more from the forecast direction when the average wind speed or gusts exceed 15 knots, an amendment must be issued.

3. When thunderstorms were not forecast but later occur or are expected to occur, or were forecast but later are expected not to occur, an amendment must be issued.

4. When precipitation that will affect flying safety (including runway breaking action) was not forecast but occurs or is expected to occur, or was forecast but later is expected not to occur, an amendment must be issued.

5. When the actual or expected altimeter setting will be lower than the minimum altimeter setting forecast (QNH), an amendment must be issued.

- *RTD* is encoded following the valid period when a TAF is transmitted at any time following the scheduled file time. This would be used when the original TAF is transmitted late, or if the original forecast is retransmitted for any reason. Occasionally, the COMEDS, PACMEDS, EURMEDS, or CARMEDS system operator sends a message to all connected terminals that the system has had a failure, and states what data has been lost. If you suspect your TAF was lost in a systems failure, it should be retransmitted as a retarded TAF. In either case, the header would read the same. As an example, we will use a late 1515 TAF from Pensacola, which would read *TAF NPA 1515 RTD.*

The Wind Forecast Group

dddff/$f_m f_m$ is the forecast surface wind direction, speed, and gust group.

- *ddd* is the forecast true wind direction (direction from which the wind is blowing) to the nearest 10 degrees. In the case of a variable wind direction, the prevailing direction is encoded for *ddd* and the limits of the variability should be appended in the remarks section; for example *WND 270V350.* In certain situations the prevailing direction cannot be determined. In these rare cases, *VRB* may be encoded in place of *ddd.* In this case, *VRB* means variable or from any direction between 001° to 360° within a short period of time. If you expect light winds from 0 to 5 knots from generally a westerly direction, but the prevailing direction is difficult to predict, the proper entry is **27003** with a remark *WND 180V360,* not *VRB03.* The term **000** should never be used as a direction when there is any wind. Due north is referred to as **360**. Encode **000** for the direction only when the wind is calm, in which case the group would read **00000**.

- *ff* is the forecast mean wind speed in whole knots. When the wind speed is forecast to exceed 99 knots, three digits are encoded, such as **121** for 121 knots.

- $f_m f_m$ is the forecast maximum wind speed or maximum gust speed in whole knots and is a mandatory entry when the mean wind speed exceeds 10 knots and the maximum wind speed or gust is 5 knots or more than the mean speed. This entry also may be encoded as three digits when greater than 99 knots. When forecasting the maximum thunderstorm gusts, or any other condition where the gust direction can be forecast, report the gust direction in the remarks section. For example, if we forecast a thunderstorm maximum gust direction of 250 degrees, we would use the remark *GUST DRCTN 250.*

Table 4-4-1.—Visibility (VVVV) Reportable Values

VVVV METERS	STATUTE MILES	NAUTICAL MILES
0000	0	0.00
0100	1/16	.05
0200	1/8	.10
0300	3/16	.15
0400	1/4	.20
0500	5/16	.25
0600	3/8	.30
0700	—	.40
0800	1/2	.45
0900	—	.50
1000	5/8	.55
1100	—	.60
1200	3/4	—
1300	—	.70
1400	7/8	—
1500	—	.80
1600	1	—
1700	—	.90
1800	1 1/8	1.0
2000	1 1/4	1.1
2200	1 3/8	1.2
2400	1 1/2	1.3
2600	1 5/8	1.4
2800	1 3/4	1.5

Table 4-4-1.—Visibility (VVVV) Reportable Values—Continued

VVVV METERS	STATUTE MILES	NAUTICAL MILES
3000	1 7/8	1.6
3200	2	1.7
3400	—	1.8
3600	2 1/4	1.9
3700	—	2.0
4000	2 1/2	2.2
4400	2 3/4	—
4500	—	2.4
4700	—	2.5
4800	3	2.6
5000	—	2.7
6000	4	3.0
7000	—	4.0
8000	5	4.3
9000	6	5.0
9999	≥ 7	≥ 6.0

The Forecast Visibility Group

VVVV is the forecast prevailing visibility in meters, rounded down to the nearest reportable value in table 4-4-1. An obstruction-to-vision type of weather (*w′w′*) must follow whenever the visibility is forecast at or less than 9,000 meters (6 statute miles).

When you are decoding the visibility group, you may find it easier to divide the *VVVV* by 16 to obtain the visibility in statute miles, than to look it up.

Table 4-4-2.—Weather and Obstructions to Vision

CODE	ELEMENT
04FU	Smoke
05HZ	Haze
06HZ	Dust in suspension, not raised by the wind at or near the station
07SA	Duststorm or sandstorm
08PO	Dust Devils
10BR	Mist (thin fog)-VVVV $\geq$1,000 meters but <5,000 meters
11MIFG	Shallow (ground) fog, in patches (<2 meters on land, <10 meters at sea)
12MIFG	Shallow (ground) fog, continuous (<2 meters on land, <10 meters at sea)
17TS	Thunderstorms, no precipitation
18SQ	Squalls
19FC	Funnel cloud, tornado, or waterspout
30SA	Dust/sandstorm, light/moderate, increasing
31SA	Dust/sandstorm, light/moderate, no change
32SA	Dust/sandstorm, light/moderate, decreasing
33XXSA	Dust/sandstorm, heavy, increasing
34XXSA	Dust/sandstorm, heavy, no change
35XXSA	Dust/sandstorm, heavy, decreasing
36DRSN	Drifting Snow, light/moderate
37DRSN	Drifting Snow, heavy
38BLSN	Blowing Snow, light/moderate
39BLSN	Blowing Snow, heavy
42FG	Fog/Ice Fog, thinning, sky visible
43FG	Fog/Ice Fog, thinning, sky not visible
44FG	Fog/Ice Fog, no change, sky visible
45FG	Fog/Ice Fog, no change, sky not visible
46FG	Fog/Ice Fog, thickening, sky visible
47FG	Fog/Ice Fog, thickening, sky not visible
48FZFG	Fog, depositing rime, sky visible
49FZFG	Fog, depositing rime, sky not visible
50DZ	Drizzle, light, intermittent
51DZ	Drizzle, light, continuous
52DZ	Drizzle, moderate, intermittent
53DZ	Drizzle, moderate, continuous
54XXDZ	Drizzle, heavy, intermittent
55XXDZ	Drizzle, heavy, continuous
56FZDZ	Drizzle, freezing, light
57XXFZDZ	Drizzle, freezing, moderate/heavy
58RA	Mixed Drizzle and Rain, light
59RA	Mixed Drizzle and Rain, moderate/heavy
60RA	Rain, light, intermittent
61RA	Rain, light, continuous
62RA	Rain, moderate, intermittent
63RA	Rain, moderate, continuous
64XXRA	Rain, heavy, intermittent
65XXRA	Rain, heavy, continuous
66FZRA	Rain, freezing, light
67XXFZRA	Rain, freezing, heavy/moderate
69XXRASN	Rain/drizzle with snow, mod heavy
70SN	Snow, light, intermittent
71SN	Snow, light, continuous
72SN	Snow, moderate, intermittent
73SN	Snow, moderate, continuous
74XXSN	Snow, heavy, intermittent
75XXSN	Snow, heavy, continuous
77SG	Snow grains
79PE	Ice pellets
80RASH	Rain Showers, light
81XXSH	Rain Showers, moderate/heavy
82XXSH	Rain Showers, violent
83RASN	Mixed Rain/snow Shower, light
84XXRASN	Mixed Rain/snow Shower, mo heavy
85SNSH	Snow Shower, light
86XXSN	Snow Shower, moderate/heavy
87GR	Snow Grain/Ice Pellet Shower, ligh or without other precipitation
88GR	Snow Grain/Ice Pellet Shower, mo with or without other precipitation
89GR	Hail Shower, light, with or withou precipitation
90XXGR	Hail Shower, moderate/heavy, v without other precipitation
91RA	Rain, light, from dissipated thunde clouds
92XXRA	Rain, moderate/heavy, from dis thunderstorm clouds
93GR	Mixed Liquid/Frozen precipitation from dissipated thunderstorm clou
94XXGR	Mixed Liquid/Frozen precipitation erate/heavy, from dissipated thunde
95TS	Thunderstorm with Rain or Snow moderate
96TSGR	Thunderstorm with Hail, light/mo
97XXTS	Thunderstorm with Rain or heavy
98TSSA	Thunderstorm with Dust/sandstor
99XXTSGR	Thunderstorm with Hail, heavy

The Forecast Weather and Obstructions to Visibility Group

w'w' is the forecast weather and obstruction to vision from table 4-4-2. Up to eight letters and numbers may be used for each *w'w'* encoded.

Normally, only one *w'w'* group is needed to describe the weather. If necessary to adequately describe the forecast weather, multiple weather groups may be used. For example, if you were forecasting 1/2 mile visibility in moderate snow, fog, and drifting snow, you could encode *800 73SN 46FG 38BLSN*. However, the wind forecast with reported snow falling would imply blowing snow, so the *38BLSN* group would not be absolutely necessary. Both the *73SN* and the *46FG* are significant conditions and should be encoded. In most cases though, the forecast prevailing weather condition can be encoded as one group, and *INTER* or *TEMPO* groups can be used to explain additional weather conditions.

When you use a change group (*GRADU*, *RAPID*, *TEMPO*, *INTER*) to indicate an end to a weather condition or an obstruction to vision, use *WX NIL* in place of the *w'w'*.

Although not listed in table 4-4-2, all of the 40 series codes apply to fog reducing visibility to less than 1,000 meters (5/8 statute mile). Use figure *10BR* when fog is forecast but the visibility will be 1,000 meters to 4,800 meters (3 statute miles), even if the sky will be obscured by the fog. If diffuse fog is forecast and the visibility is expected to be 5,000 meters (3 5/8 statute miles) or greater, use figure *05HZ* for the *w'w'* group.

The Forecast Cloud Layer Group

$N_SCCh_Sh_Sh_S$ is the forecast cloud layer group. This group may be repeated as often as necessary in each section of the forecast to describe all the cloud layers forecast. The groups are arranged in ascending order from the lowest to the highest. When skies are forecast to be clear, encode *SKC* (for sky clear) in place of this group. The coding of each of the three elements that make up this group is as follows:

- N_S is the amount of the cloud in the layer, in eighths. The *summation principle* does not apply. You may, for instance, forecast a low overcast (8 eighths) with another overcast layer (8 eighths) on top of that and a broken layer (5 eighths) above that one, for a total of 21 eighths.

- *CC* is the forecast cloud type. Use table 4-4-3 for the two-letter code for the cloud type.

- $h_Sh_Sh_S$ is the forecast height of the cloud base above the surface (AGL), in hundreds of feet. Cloud bases are forecast to the nearest 100 feet from the surface to 5,000 feet; to the nearest 500 feet between 5,000 feet and 10,000 feet; and to the nearest 1,000 feet above 10,000 feet. For example, a cloud base forecast at 400 feet would be encoded as **004**, while a cloud base forecast at 6,500 feet would be encoded as **065**.

The ceiling is defined as the layer at which clouds at and below the layer cover more than 4 eighths of the sky. Whenever a forecast layer constitutes a ceiling, identify that layer as a ceiling by adding the group $CIGh_Sh_Sh_S$ in the remarks section of that portion of the forecast. Always include this group for a total obscuration.

When the forecast total cloud amount is more than 4 eighths, but will not constitute a ceiling, use the term *CIGNO* in the remarks section. For example, this would be the case when forecasting 4 eighths of cumulus at 2,500 feet and 6 eighths of thin cirrostratus at 30,000 feet. Thin layers, or the portion of a layer that is thin, are not considered when designating a ceiling. In another situation, you may forecast several opaque layers of clouds that may each total 4 eighths, but are vertically stacked and together do not cover 5 eighths or more of the total dome of the sky, so no ceiling would be present.

You may forecast several different types of clouds with bases at the same level. Normally, encode only the predominant cloud as the cloud type, and use the total cloud coverage at that level for the cloud amount. The exception to this is

Table 4-4-3.—Cloud Type (CC)

CC	CLOUD TYPE
NS	Nimbostratus
ST	Stratus
SC	Stratocumulus
CU	Cumulus
CB	Cumulonimbus
AS	Altostratus
AC	Altocumulus
CI	Cirrus
CS	Cirrostratus
CC	Cirrocumulus

if the layer is composed of mixed cloud types which include cumulonimbus, such as 3 eighths of cumulus at 2,000 feet, 2 eighths of stratocumulus at 2,000 feet, and 1 eighth of cumulonimbus at 2,000 feet. When this situation occurs, encode cumulonimbus separately as the first group, and the total of the other cloud(s) next. Using this as an example, we would encode *1CB020 5CU020.*

When the sky will be totally obscured by a phenomena such as fog or precipitation, encode N_S as *9*, *CC* as *//*, and $h_Sh_Sh_S$ as the vertical visibility in hundreds of feet. For example, an obscuration at 200 feet caused by snow would be encoded as *9//002*, and *CIG002* would be used in the remarks section.

Although there is no direct provision in the TAF code for forecasting partial obscurations, you should indicate them by using an $N_SCCh_Sh_Sh_S$ group in the remarks section. For example, if 5 eighths of the sky is forecast to be obscured by fog, we would use *5FG///* in the remarks section. The obscuring phenomena should be the same as the one used to forecast the restriction to visibility. When used, this remark will immediately follow any $CIGh_Sh_Sh_S$ remark; otherwise, it should be the first remark. In this example, the fog covers more than 4 eighths of the sky, so it would be designated as a ceiling and we would encode *CIG005 5FG///* as the first two entries in the remarks section.

When the total cloud amount is forecast to be less than 4 eighths but the partial obscuration will cause the total sky cover to be greater than 5 eighths, then the first layer of clouds, which, when added to the partial obscuration, totals 5 eighths or more, should be designated as the ceiling. For example, mist is forecast to reduce the visibility to 2,000 meters and will cause a partial obscuration of 3 eights of the sky, but the only cloud forecast is 2 eighths of stratocumulus at 2,500 feet (and the minimum altimeter forecast is 30.25 inches) you would encode *2000 10BR 2SC025 QNH3025INS CIG025 3BR///.*

When you forecast two or more significant sky conditions that will alternate frequently, such as 3 eighths of clouds at a level alternating with 5 eights of clouds at that level, or 5 eights of cloud frequently alternating between 3,000 feet and 2,500 feet, use an *INTER* group (for intermittent conditions) in remarks to describe the situation. Do not use the term *VRBL* or *V* (for variable conditions) to describe any sky conditions in the TAF code.

If thunderstorms or cumulonimbus clouds are not forecast at the station but may affect aircraft approaching, departing, or operating in the vicinity of the station, you should include an appropriate remark in the remarks section to describe the situation, such as *TS VCNTY* or *CB OMTNS W.*

Although you may receive TAF forecasts from outside CONUS that include the group *CA VOK*, meaning ceiling and visibility OK (the visibility is 10,000 meters or greater; there are no clouds below 1,500 meters; no cumulonimbus clouds at any height; and there is no precipitation, ground fog, or drifting/blowing snow), in place of both the visibility (*VVVV*) and the cloud layer ($N_hCCh_Sh_Sh_S$) groups, this term is not an acceptable entry for use by forecasters within the continental United States. Overseas U.S. military personnel may use the term if allowed by the host country's regional regulations. The term *CA VU*, meaning ceiling and visibility unlimited (visibility greater than 10 statute miles and no ceiling lower than 10,000 feet) is a term that is no longer allowed for use by any WMO member nation.

The Forecast Surface Air Temperature Group

$0G_fG_fT_fT_f$ is the forecast surface air temperature group. It is included only in the sections of the forecast where necessary. Normally it is used to forecast the minimum temperature in the section of the forecast covering the period of time when the minimum temperature is expected to occur, and to forecast the maximum temperature in the portion of the forecast covering the period of time when the maximum temperature is expected to occur. It may be used as often as necessary within the forecast to indicate significant temperatures.

- *0* is the group indicator of the temperature forecast.

- G_fG_f is the valid time, to the closest whole hour, of the temperature forecast.

- T_fT_f is the forecast temperature in whole degrees Celsius, which is always encoded in two digits. Prefix a freezing temperature forecast with an *M*. For example, −7 °C forecast to occur at 1015Z is encoded as *010M07.*

The Forecast Icing Group

$6I_ch_ih_ih_it_L$ is the forecast icing group that is used whenever any type of icing condition is forecast outside of thunderstorms (thunderstorms

imply moderate or greater icing). Omit the group when no icing is forecast. Use as many groups as necessary to describe all layers of expected icing.

- *6* is the icing group indicator.

- I_c is the icing type and intensity code from table 4-4-4. When forecasting icing where either the intensity or the type are borderline conditions, use the higher code figure.

- $h_ih_ih_i$ is the height of the base of the icing layer in hundreds of feet above the surface (AGL), rounded down to the lowest hundred. For example, if you forecast an icing layer base at 395 feet, you would encode **003**.

- t_L is the thickness of the icing layer in thousands of feet, rounded up to the nearest thousand feet. For example, you forecast moderate mixed icing from 730 feet to 1,800 feet (the layer is actually 1,070 feet thick), you would round up and encode t_L as **2**. The group would read **640072**. If an icing layer exceeds 9,000 feet in thickness, repeat the entire group using the top of the lower 9,000-foot layer as the base of the next layer.

The Forecast Turbulence Group

$5Bh_Bh_Bh_Bt_L$ is the forecast turbulence group that is encoded to report all forecast levels of turbulence other than that in thunderstorms (thunderstorms imply severe or extreme turbulence). Omit the group when no turbulence is forecast. Use the group as many times as necessary to cover all turbulence conditions.

- *5* is the turbulence group indicator.

- *B* is the turbulence type and intensity code from table 4-4-5.

The term *occasional* in table 4-4-5 means less than one-third of the time.

- $h_Bh_Bh_B$ is the height of the base of the turbulence layer above the surface (AGL) in hundreds of feet, rounded down to the nearest hundred.

- t_L is the thickness of the turbulence layer in thousands of feet, rounded up to the nearest thousand. When a layer exceeds 9,000 feet, encode a second group using the top of the 9,000-foot layer in the last group as the base of the layer in the second group.

When *extreme* turbulence is forecast, use the turbulence group in the forecast (reporting code figures 6, 7, 8, or 9), and add *EXTRM TURB*

Table 4-4-4.—Icing Type and Intensity (I_c)

CODE FIGURE	TYPE OF ICING
0	Trace of any icing
1	Light Mixed icing
2	Light Rime icing
3	Light Clear icing
4	Moderate Mixed icing
5	Moderate Rime icing
6	Moderate Clear icing
7	Severe Mixed icing
8	Severe Rime icing
9	Severe Clear icing

Table 4-4-5.—Turbulence Type and Intensity (B)

CODE FIGURE	TYPE/INTENSITY OF TURBULENCE
0	None
1	Light in clear air or cloud
2	Light occasional moderate in clear air
3	Moderate in clear air
4	Light occasional moderate in cloud
5	Moderate in cloud
6	Moderate occasional severe in cloud
7	Severe in clear air
8	Moderate occasional severe in cloud
9	Severe in cloud

$h_Bh_Bh_B$-$h_th_th_t$ to the remarks section. The $h_Bh_Bh_B$ is the height of the base of the layer; $h_th_th_t$ is the height of the top of the layer in hundreds of feet.

The Forecast Minimum Altimeter Setting Group

QNH$P_2P_2P_2P_2$*INS* is the forecast minimum altimeter setting group. This group is used in the initial forecast period and for each section of the forecast covered by the change groups *GRADU* and *RAPID*. It is not included in forecast modifier sections identified by the terms *INTER* or *TEMPO*.

- *QNH* is the identifier that a minimum altimeter setting (minimum sea level pressure) follows. Certain regions in the Mid-East and Africa report *QFE* instead of *QNH*. *QFE* is the station pressure.

- $P_2P_2P_2P_2$ is the forecast lowest altimeter setting that will occur during the period of time covered by that section of the forecast. It is entered to the nearest hundredths of an inch with the decimal point deleted.

- *INS* is the units indicator for inches.

As an example, the lowest forecast altimeter for a forecast period is 29.87 inches; this group would be entered as *QNH2987INS*.

Learning Objective: Identify the types of remarks that may be used within a TAF.

REMARKS

Remarks may be entered following the minimum altimeter setting forecast group *QNH* whenever the forecaster feels the remarks are significant. As we discussed previously, these remarks may include ceiling designation; visibility variations statements; modified cloud groups to encode partial obscurations; wind variation statements; maximum wind gust direction; the levels of extreme turbulence; or statements such as *TSTMS OVR MTNS W*, *TSTMS VCNTY*, or *FG OVR RIVER EAST*. Generally, any item that is significant for flying safety and is not covered by the forecast may be entered as a remark. All remarks should use standard abbreviations and contractions as contained in *Contractions*, FAA Handbook 7340.1, commonly referred to as the Contractions Manual. This publication is available from the DMA Combat Support Center in Washington, D.C.

All remarks should be entered in order. The first remark is always the ceiling designation, followed by the modified group for partial obscurations. The remainder of the remarks should be arranged in the order that the code group appears in the code format.

Learning Objective: Identify the different change groups and state when these groups should be used in the TAF.

CHANGE GROUPS

Change groups are used to indicate a change in any or all elements from the predominant forecast and are followed by the description of all the elements that are forecast to change. Each change group indicates the time during which the changes are forecast to occur. When used, a change group will begin on a new line. The TAF code uses four change groups; *RAPID*, *GRADU*, *TEMPO* and *INTER*. *RAPID* and *GRADU* are used to indicate any change in the prevailing condition that will last for at least 1 hour. These groups establish a new set of prevailing conditions. *TEMPO* and *INTER* are used as remarks to indicate short-lived changes in the prevailing conditions which will individually last for less than 1 hour.

- *RAPID GG* is used to describe a change in prevailing conditions that will take place during a period of time less than 1/2 hour. The *GG* is the last whole hour UTC before the change begins. This group must be followed by a complete description of the conditions that will prevail after the change. The wind, visibility, weather, cloud, and minimum altimeter setting groups must all be included. Remarks may follow the altimeter setting group. A pertinent remark indicating the reason for the rapid change may also be included, such as *CLD FROPA* for a cold frontal passage.

- *GRADU GGG*$_e$*G*$_e$ describes a change in the prevailing conditions that will take place

during a period of time lasting more than 1/2 hour but less than 2 hours. The group is followed by a complete description of the prevailing conditions after the change occurs and must include the wind, visibility, weather, cloud and minimum altimeter setting groups, as well as any pertinent remarks.

GGG_eG_e is the forecast period indicator. GG is the last whole hour UTC before any change is forecast to occur, and G_eG_e is the first whole hour UTC after the changes end (up to 2 hours later than GG). The period must cover the entire time during which the conditions will be changing. If the forecast changes will occur over more than a 2-hour period, two or more *GRADU* change groups should be used. The first change group may cover a 2-hour period and describe the conditions that will prevail at the end of the change period, and the second period should cover any change during the following period lasting up to 2 hours, etc. If we are forecasting a gradual change in conditions over a 3-hour period from 0430Z to 0730Z, the forecast should be formatted as follows:

> GRADU 0406 $dddff/f_mf_m$ VVVV w'w' $N_SCCh_Sh_Sh_S$ $OG_FG_FT_FT_F$ $6I_Ch_ih_ih_it_L$ $5Bh_Bh_Bh_Bt_L$ $QNHP_2P_2P_2P_2INS$ (Remarks)
> GRADU 0608 $dddff/f_mf_m$ VVVV w'w' $N_SCCh_Sh_Sh_S$ $OG_FG_FT_FT_F$ $6I_Ch_ih_ih_it_L$ $5Bh_Bh_Bh_Bt_L$ $QNHP_2P_2P_2P_2INS$ (Remarks)

- *TEMPO* GGG_eG_e is the change group used to indicate temporary changes in a prevailing forecast condition. Each change from the predominant condition should last less than 1 hour, and if the change is to occur more than once, the total time of all the occurrences should not exceed one-half the total time covered by the forecast period indicated by GGG_eG_e. When using this group, it is followed only by the description of the elements that are forecast to be different from the predominant conditions during the period. It should not include a *QNH* group, but may include any pertinent remarks.

GGG_eG_e is the forecast period indicator. GG is the last whole hour UTC before any change is forecast to occur, and G_eG_e is the first whole hour UTC after the changes end. The period must cover the entire time during which the conditions will be different from the forecast prevailing conditions.

- *INTER* GGG_eG_e is the change group used to indicate intermittent changes from a predominant forecast condition. Intermittent changes occur more frequently than temporary changes and last for shorter periods of time. All occurrences together must last less than half the total time covered by the forecast period. This group is followed by a description of only those conditions that will be different from the prevailing conditions, including ceiling designation and pertinent remarks.

At this point, you should be able to *read* a TAF coded report. An example of a TAF for NAS Pensacola (Sherman Field) is provided along with an explanation of the coded forecast. As you go through the coded forecast, determine what each code group actually means. Compare your interpretation with the explanation.

```
NPA 1515 COR 12005 4000 10BR 3ST005 7ST012
   QNH3001INS CIG005 2BR///

TEMPO 1517 00000 0800 45FG 9//001

GRADU 1820 20015 4800 81XXSH 3CU015 3AC120
   4CS250 01918 651206 QNH2995INS CIG120 TS
   VCNTY

TEMPO 2123 24015/45 0800 97XXTS 2CB010 3CU010
   8AC080 8CS250 CIG010 GUST DRCTN 330

RAPID 23 34025 9999 WX NIL 3SC025 2CS250 520002
   QNH3000INS CIGNO LLWS TIL 01Z CLD FROPA

INTER 2301 8000 80RASH 2CU020 CIG025

GRADU 0103 34015 9999 WX NIL SKC QNH3006INS
   WND 32005 AFT 05Z

GRADU 1011 32003 6000 05HZ 01208 QNH3012INS

GRADU 1415 33009 9999 WX NIL SKC QNH3010INS

COR 1544;
```

Explanation:

The corrected forecast is for NAS Pensacola, Florida (NPA), valid from 1500Z to 1500Z.

The initial condition (1500Z to 2000Z) forecasts winds from 120° at 5 knots, visibility 2 1/2 miles (4,000 meters) in fog (mist), sky cover 3/8 stratus (fractus) at 500 feet, 7/8 stratus at 1,200 feet, minimum altimeter 30.01 inches, ceiling 500 feet due to the partial obscuration by fog of 2/8 of the sky (2BR///) plus the 3/8 of stratus fractus at 500 feet.

During the period between 1500Z and 1700Z, the above conditions will deteriorate briefly to calm winds and 1/2 mile visibility in fog, with an obscured ceiling at 100 feet.

Between 1800Z and 2000Z, the conditions will gradually change and become, by 2000Z, winds from 200° at 15 knots, visibility 3 miles (4,800 meters) in moderate to heavy rain showers. The sky cover will be 3/8 cumulus at 1,500 feet, 3/8 of altocumulus forming a ceiling at 12,000 feet and 4/8 cirrostratus at 25,000 feet, with moderate rime icing (in cloud) from 12,000 feet to 18,000 feet. The maximum temperature will be 18 °C at 1900Z. The minimum altimeter setting will be 29.95 inches. Thunderstorms will be in the area, but not over the airfield except between 2100Z and 2300Z. During this period, thunderstorms will briefly affect the airfield, producing winds from 240° at 15 knots, with a maximum gust expected from 330° at 45 knots. Visibility will lower to 1/2 mile (800 meters) in rain during the thunderstorm, and the ceiling will be at 1,000 feet, due to 2/8 cumulonimbus and 3/8 cumulus. Altocumulus will also form a temporary 8,000-foot overcast and cirrostratus will form an additional overcast layer at 25,000 feet.

Rapid changes will take place with a cold frontal passage at 2300Z or shortly thereafter, so that by 0000Z the wind will be from 340° at 25 knots, with unrestricted visibility and no significant weather with 3/8 of stratocumulus at 2,500 feet and 2/8 of cirrus at 25,000 feet. Apparently, the cirrus will be thin, since there will not be a ceiling. The strong winds will cause light, occasional moderate low-level turbulence in the clear air from the surface to 2,000 feet, and Low Level Wind Shear is expected to be present until 0100Z. The minimum altimeter setting will be 30.00 inches. Also, up until 0100Z, there will be frequent, but brief light rain showers, lowering the visibility to 5 miles (8,000 meters) with associated 2/8 cumulus clouds at 2,000 feet causing a ceiling at 2,500 feet (when added to the 3/8 stratocumulus predominant layer).

Between 0100Z and 0300Z, the conditions will gradually improve. By 0300Z, the wind will be from 340° at 15 knots, with unrestricted visibility, no significant weather, no clouds, and a minimum altimeter setting of 30.06 inches. After 0500Z, the winds will decrease to 320° at 5 knots.

Thin fog will gradually form between 1000Z and 1100Z, lowering the visibility to 4 miles (6,000 meters), with the wind from 320° at 3 knots. The minimum temperature will be 8 °C near 1200Z.

Between 1400Z and 1500Z, the fog will clear as the winds increase to 330° at 9 knots, resulting in unrestricted visibility and clear skies, with a minimum altimeter setting of 30.10 inches.

SUMMARY

The TAF coded forecast provides information about your airfield's expected weather conditions to worldwide users. When composing a TAF, you must insure that it completely and accurately describes the conditions you expect to occur for the next 24 hours. Each TAF contains a header that is used to identify the forecast location as well as the valid period of the forecast. Different groups are used within the TAF code to describe various weather elements. Remarks and change groups are used to modify the basic forecast.

UNIT 4—LESSON 5

TACTICAL ENVIRONMENTAL SUPPORT SYSTEM (TESS) PRODUCTS

OVERVIEW

Identify the five basic functions of TESS.

Identify the products available from TESS.

OUTLINE

The basic TESS functions

TESS operation and program products

TACTICAL ENVIRONMENTAL SUPPORT SYSTEM (TESS) PRODUCTS

In this lesson we will discuss a general overview of the TESS 2.1 operation and products. Your main objective is to be able to identify what products are available from TESS, so you will know what is available for your use. In achieving this objective, you may also acquire a general understanding of the TESS concept. The intent of this lesson is not to make you into a qualified TESS operator or a qualified TESS interpreter/briefer. We will leave that job to the formal NEC-yielding TESS Operator course (NEC 7416) and TESS Interpreter/Briefer course (NEC 7418).

More detailed information on the various programs and output from TESS 2.1 is contained in the Tactical Environmental Support System *TESS 2.1 Users Guide*, volumes 1 and 2, available from the Naval Oceanographic Office.

The next upgrade to TESS, TESS 3, is tentatively identified as AN/UMK-3(XN-1), and is scheduled for Fleet delivery in 1991.

CAUTION

With the exception of the information contained in this lesson, information concerning the programs, equipment, data files, and location of operational TESS systems is considered critical technology and may not be discussed or released outside U.S. Department of Defense channels. Certain software may also be classified and have additional, more restrictive, distribution limitations.

The Tactical Environmental Support System (TESS) provides tailored meteorological, electromagnetic propagation, oceanographic, acoustic, and satellite products in direct support of Fleet air and surface planning and operations and antisubmarine warfare (ASW) operations. Specifically, TESS provides the capability to assess the effects of the environment on fleet sensors, platforms, and weapons systems. All TESS products are provided within a time frame consistent with the validity of the data and their practical potential for tactical exploitation. The analyses and predictions are based on on-scene data, data received via teletype communications, satellite data, shore-based analyses and predictions, historical data, threat characteristics, and weapon/sensor characteristics.

TESS is a rapid-response, on-scene, environmental prediction system used to quickly determine the effect of the environment on Fleet weapon/sensor systems. Locally collected meteorological information is used to prepare analyses of present atmospheric and electromagnetic propagation conditions. Locally collected oceanographic information is combined with archived data to prepare an analysis of existing oceanographic and acoustic conditions. Weapon/sensor system parameters are then factored in, to produce displays that show the effects of the environment on these systems. These displays can be used by tactical commanders and planners in decision making. Not only does TESS provide the most valid performance predictions when current data is available covering the area of interest, it can also provide *best guess* predictions, using data stored in the data base.

Learning Objective: Identify the five basic functions of TESS.

THE BASIC TESS FUNCTIONS

TESS is composed of five basic functions:

- Environmental data assimilation
- Environmental analysis
- Sensor/weapon systems performance prediction
- Briefing support data preparation
- Data file generation and maintenance

In the *environmental data assimilation* function, TESS accepts locally acquired environmental data from various sources, catalogs the data, processes the data, then writes the data to available data files for use by other functions. This data includes (1) meteorological and oceanographic data received via teletype interface; (2) raw satellite (imagery) data received via the SMQ-6 satellite receiver station interface; (3) operator-entered surface, radiosonde, refractivity, and bathythermograph data; and (4) refractivity data entered through the Airborne Microwave Refractometer interface. This function also checks the quality of the environmental data in order to maximize the validity of the results of the application programs.

The TESS *environmental analysis* function generates analyses of existing environmental conditions affecting air, surface, and antisubmarine warfare operations. These analyses are performed by atmospheric analysis, meteorological, and oceanographic application programs. The analyses data are presented in the form of graphic and tabular displays, which can be hard-copied and used for performance predictions.

The *sensor/weapon systems performance prediction* function of TESS provides the capability to predict the performance of air, surface, and ASW sensor/weapon systems, based on analyzed environmental data and sensor/weapon system characteristics. Data is produced that defines the predicted effective range/coverage sensitivity, detectability, and accuracy of specific sensor/weapon systems, for both friendly and hostile forces. The predictions quantify the effects of environmental conditions on systems performance and directly influence asset employment decisions. The results are displayed in graphic or tabular form, and they can be hard-copied as necessary.

The TESS *briefing support data presentation* function allows the operator to assemble, package, and present data to be used for mission planning and briefing purposes. Tabular and graphic displays produced by the *environmental analysis* and *sensor/weapon systems performance prediction* functions can also be accessed by this function. The important feature of this function is that it allows operators to tailor products so that mission crews receive all of the necessary information to perform their mission. All of the output information is presented in a form that is readily understood and usable by mission crews.

The TESS *data file generation and maintenance* function provides the capability to create, maintain, and/or delete data files. Some of the data files are permanent in nature and are provided by shore-base sites. These include bottom topography, coastal geography, weapon/sensor system characteristics, and climatological data. These files are maintained and used for long periods of time and are changed only when updates are received from the software support activity. Other files are created by the operator, based on locally available information (for example, briefing scenarios and non-standard weapon/sensor systems or platform characteristics). Still other files are transitory because of the perishable data that they contain (for example, atmospheric, refractivity, and oceanographic data files). Implicit in this function is the capability to ensure the integrity of the data files and to provide adequate safeguards to any classified data in the files. The ability of this function to perform its described duties is not dependent on extensive operator knowledge of the file structure or file data format.

Learning Objective: Identify the products available from TESS.

TESS OPERATION AND PROGRAM PRODUCTS

The TESS 2.1 system has three terminals, so it can be operated by up to three users at a time.

When TESS is first entered, the TESS main menu is displayed. This menu allows the operator to select the category of application program to be run. TESS has nine categories of application programs: Analysis Utilities, Atmospheric Analysis, Meteorology, Electromagnetic Propagation, Oceanography, Acoustics, Message Composing, Satellite Applications, and Briefing Support. We will discuss these categories and their individual program modules in the remainder of this lesson.

Analysis Utilities Programs

The TESS Analysis Utilities category is composed of the Solar/Lunar Almanac, Map Creation, Teletype Message Management, and Contour Digitization programs.

The *Solar/Lunar Almanac Program* (SLAP) produces monthly or daily summaries of ephemeral data for the Sun and Moon. These summaries include the times of sunrise and sunset and moonrise and moonset, the beginning and ending of civil and nautical twilights, the total daylight and daily illuminance, the phase of the Moon in percent illumination, the time and altitude of the Sun's and the Moon's meridional passage, and the hourly altitude and azimuth measurements for the Sun and the Moon.

The *Map Creation* program provides the capability to draw and store up to 10 Mercator, polar-stereographic, and Lambert Conformal maps for operator-designated areas. These maps can be used by programs such as *Warnings Plot* for display of processed data. Within the applications, the operator can choose a map area and then "zoom-in" or "zoom-out" on a specific area of the map.

The *Teletype Message Management* (TMM) program receives and processes data input from the teletype interface. For shipboard TESS systems, four channels are provided for this information. One channel is dedicated to handling data received from the U.S. Navy Fleet Broadcast, while the other three channels receive indigenous foreign or U.S. radioteletype broadcasts of environmental data. At shore sites, TESS interfaces with the local Meteorological and Environmental Data System (MEDS) input teletype data, which includes World Meteorological Organization (WMO) codes, Airways codes, Plain Language messages, and other bulletins. The *Teletype Message Management* program operates 24 hours a day processing all teletype data received. It also allows manual input of coded environmental observations. All incoming traffic is automatically sorted, with unwanted messages being directed to a temporary contingency file. Coded messages are checked for syntax errors, quality checked, and stored for later retrieval by other application programs or by the operator. Application programs requiring teletype data observations (stored in their coded formats) access appropriate *decode* utility programs in order to decode the necessary data fields.

The *Contour Digitization* program provides the capability to digitize facsimile charts or other analyses for display and for use as a first-guess field for the *Weather Analysis* program. Digitized contours are entered as arrays of latitude and longitude for the appropriate contour values via the digitizer and keyboard. The arrays are then made available for display and storage in the *Environmental Data Files* (EDF).

Atmospheric Analysis Programs

The TESS Atmospheric Analysis section is composed of four programs: Observation Plot, Weather Analysis Warnings Plot, and Local Observation Entry and Archival.

The *Observation Plot* (OBSPLOT) program allows the operator to plot selected atmospheric parameters, one at a time, for a given atmospheric isobaric level, date, time, and geographic area. This function accesses the TMM decode utilities to extract parameters of interest from the coded observations. Observations are spatially thinned during plotting in order to prevent overwriting.

The *Weather Analysis* program provides the forecaster with an interactive operational system for numerical analysis of meteorological fields. The analysis scheme performs several interactive scans to fit irregularly spaced observation data to an initial first-guess field, so that representative values may be obtained anywhere within the analysis region. The analysis takes the form of an ordered array of grid point values and is available for display and storage. The display consists of a contoured objective analysis of the desired field (pressure, geopotential height, wind, etc.) at an operator-specified date, time, level, and geographic region.

The *Warnings Plot* program provides the capability to enter and display tropical cyclones, high-wind and high-seas warning message data. The *Tropical Cyclone* program provides the capability to display storm track forecasts, to compare storm track forecasts, and to verify storm forecasts. With the exception of the *Storm Verification* subroutine, all displays are provided

on an operator-selected map background. Additionally, outputs are routed to the briefing support data files for later recall and use.

The *Local Observation Entry and Archival* (LOEA) program provides the capability to enter, edit, and archive local surface weather observations; display surface weather observations on a standard surface weather observation form, as an airways coded message, or in a synoptic coded message format; archive and retrieve radiosonde data sets and refractivity data sets; and to convert relative wind speed and direction to true wind.

Meteorological Programs

The TESS Meteorological programs section is composed of Radiosonde Initial Analysis, D-Values, Sound Focus, Ballistic Winds and Densities, Radiological Fallout, Aircraft Icing, Ship Ice Accretion, and Tomahawk Environmental Support.

The *Radiosonde Initial Analysis* (RIA) program is used to enter upper-air data into TESS and to compute profiles of wind and thermodynamic data for use by the *Electromagnetic Propagation* program and other meteorological programs. This program receives inputs in the form of raw ordinate values profiles, profiles of pressure, temperature, and humidity, or encoded upper-air messages. Outputs consist of profiles of pressure, temperature, dew point temperature, relative humidity, geopotential height, wind speed, wind direction, and modified refractivity (M-units). The program also computes the Lifting Condensation Level (LCL), Convective Condensation Level (CCL), Level of Free Convection (LFC), Freezing Level, Showalter Stability Index (SSI), and contrail formation data. Encoded messages are provided when the inputs are in the form of raw ordinate values. Skew T, Log P Diagrams are produced upon request.

The *D-Value* program is used to compute profiles of D-Values, which are used in setting pressure-bomb detonation altitudes and other applications.

The *Sound Focus* (SOCUS) program forecasts sound propagation in the atmosphere. Sound focus forecasts allow Fleet personnel to determine if atmospheric conditions favor large-scale refraction of sound toward populated areas during naval gunfire, bombing, and explosives exercises.

The *Ballistic Winds and Densities* (METBAL) program computes and outputs ballistic wind and density correction factors. These factors are used to obtain first-shot-on-target delivery of naval gunfire rounds.

The *Radiological Fallout* (RADFO) model forecasts patterns of radiological fallout, which are ~~used to~~ determine ship ~~and unit~~ maneuvers in the event of a nuclear burst.

The *Aircraft Icing* (AIRICE) program determines icing levels, probabilities, and intensities used in pilot briefings and electrooptic sensor/weapon systems employment planning.

The *Ship Ice Accretion* (SHIP ICE) program provides estimates of ship ice accretion rates. Ice accretion from sea spray on a ship's superstructure can impair the operational capability and safety of the ship.

The *Tomahawk Environmental Support* program provides the capability to compute environmental inputs necessary for Tomahawk employment. Program inputs are supplemented with *Tomahawk Environmental Support Product* (TESP) messages received from the Fleet Numerical Oceanography Center.

Electromagnetic Propagation Programs

The Electromagnetic (EM) Propagation section is composed of five major categories of programs: Environmental Status, Files Maintenance, Propagation Conditions, Electromagnetic Applications, and Electrooptical Applications.

ENVIRONMENTAL STATUS.—The Environmental Status option is used to assess the status of the refractivity data file. An existing refractivity data set may be selected for use, or one can be created using the *Create Atmospheric Refractivity Data Set* (CARDS) program. Refractivity data sets consist of a profile of a modified refractive index with respect to height (M-units), the evaporation duct height, and surface wind speeds. Refractivity data sets can be created using one of four methods: direct M-unit profile entry, radiosonde data selection, historical refractive profile data selection, or Airborne Microwave Refractometer data analysis.

FILES MAINTENANCE.—The *File Maintenance* option provides the capability to edit the EM systems data files. These files contain system information, and provide information that is used as inputs to the various EM System Application functions. The EM system data files consist of the *Platform* file, the *Jammer* file, and the *ESM Receiver* file.

PROPAGATION CONDITIONS.—The Propagation Conditions program provides the capability to provide either an actual EM Propagation Conditions Summary or a Historical EM Propagation Conditions Summary.

The *EM Propagation Conditions Summary* (PCS) output consists of a graphical depiction of the refractive conditions, a plain language narrative describing the generalized refractive effects expected, and the proper settings for the SPS-48 surface-search radar.

The *Historical EM Propagation Conditions* (HEPC) Summary provides tables summarizing the percent occurrence of enhanced ranges, surface-based ducts and elevated ducts, an evaporation duct histogram, and a general meteorology summary. These are provided for operator-specified months and locations.

ELECTROMAGNETIC APPLICATIONS.— The Electromagnetic Applications option provides access to the following application programs: Electromagnetic Coverage; Electromagnetic Path Loss Versus Range; Surface-Search Radar Range Tables; Electronic Support Measures Range Tables; Platform Vulnerability; Battle Group Vulnerability; Electronic Countermeasures Effectiveness; Chaff Planning and Prediction; and Automode.

The *Electromagnetic Coverage* (COVER) program provides a display of radar detection or communication coverage in the vertical plane. The output diagrams provide the information necessary to plan flight profiles for airborne systems to achieve the maximum probability of detecting targets. It is also used to plan flight profiles of attacking aircraft against surface targets to minimize the probability of detection and to alert surface units to holes in their radar coverage against attacking aircraft or missiles.

The *Electromagnetic Path Loss Versus Range* (LOSS) program provides displays of electromagnetic path loss with respect to range. This program is used to assess the performance of user-specified electromagnetic systems against specific airborne targets under given atmospheric conditions and to determine maximum detection, communication, and intercept ranges.

The *Surface-Search Radar (SSR) Range Tables* program determines detection ranges of predefined U.S. and hostile surface targets for the SPS-10 and SPS-55 surface-search radars. The output ranges are for a 90% probability of detection. These ranges are used by a tactical commander to alter the disposition of the forces as necessary to maximize the effectiveness of the search effort.

The *Electronic Support Measures (ESM) Range Tables* program calculates and displays maximum intercept ranges of U.S. and hostile surface-based emitters by U.S. surface-based ESM receivers. This capability allows the development of an ESM employment plan that maximizes the potential for detecting target emitters.

The *Platform Vulnerability (PV)* and *Battle Group Vulnerability (BGV)* functions are used to assess the vulnerability of a platform or a battle group to an airborne or surface-based ESM system. Outputs are provided by bar charts and platform diagrams.

The *Electronic Countermeasures (ECM) Effectiveness* program provides a measure of airborne jammer effectiveness against a hostile surface-based radar. This program can determine the optimum locations and flight paths of attack for tactical jamming aircraft.

The *Chaff Planning and Prediction* program provides an all-encompassing routine for tactical Chaff operations that includes Chaff planning considerations, Chaff characteristics, aircraft and dispenser capabilities, real-time environmental conditions, threat parameters, and proposed Chaff tactics in a logical and operator-convenient interactive format.

Automode provides a method to quickly produce output displays for the PCS, COVER, LOSS, ECM, and Platform Vulnerability programs. Automode executes these programs in a background mode and automatically sends the output to the *Briefing Support* program. The programs are executed according to the last selections made during the individual program runs. The Briefing Support program is then used to print the displays or data into a briefing file.

ELECTROOPTICAL APPLICATIONS.— The Electrooptical Applications option provides access to the Forward-Looking Infrared range program and the Laser Range Prediction program.

The *Forward-Looking Infrared (FLIR) System Prediction* program determines the operational ranges of airborne FLIR devices against surface targets. Ranges are given as a function of height and represent a 50% probability of detection.

The *Laser Range Prediction* (LRP) program displays range information for exposures to low-level laser radiation, both by height versus range and by differences between day and night

conditions. The program also displays range versus time of exposure, for different levels of exposure to laser radiation.

Oceanographic Programs

The TESS Oceanographic programs section consists of the following programs: Sound Speed Profile; Ocean Data Analysis; Raytrace; Near-Surface Ocean Thermal Structure; Tidal Prediction; Search and Rescue; and Magnetic Anomaly Detection (MAD) Operational Effectiveness.

The *Sound Speed Profile* (SSP) program provides surface to bottom sound speed profiles for given dates and locations for specified oceanographic conditions. This program merges on-scene expendable bathythermograph data with historical temperature and salinity data. The merged profile is converted to a sound speed profile, which is used as input to the *Near-Surface Ocean Thermal Structure*, *Ocean Data Analysis*, *Raytrace*, *Passive Acoustic Propagation Loss*, and *Sensor Performance Prediction* programs.

The *Ocean Data Analysis* (ODA) program is a tool for synoptic analysis of the ocean thermal structure, acoustic properties, and bottom characteristics. Temperature, sound speed, depth, gradient, and bottom analysis are displayed as tabular outputs, area plots, single traces, multiple traces, overlays, or vertical sections.

The *Raytrace* program produces raytrace diagrams based on the sound speed profile generated by the *Sound Speed Profile* program. The operator specifies a set of rays and the bottom topography. Bottom depth/range pairs may be automatically retrieved from the permanent data base by operator-specified bearings.

The *Near-Surface Ocean Thermal Structure* (NOTS) program is used to forecast changes in the upper ocean thermal structure due to mixing, heating, and cooling. Mixing is caused by surface winds, whereas heating and cooling are caused by heat fluxes, precipitation, and evaporation. The program outputs forecast temperature profiles with respect to depth; these profiles can be input to the *Sound Speed Profile* model for use in various TESS acoustic programs.

The *Tidal Prediction* (TIDES) model combines location-specific tide data, astronomical effects, and bathymetric effects to yield quick, reliable tidal predictions. Outputs consist of graphic and tabular depictions of tidal height versus time at individual locations, as well as tidal heights at a given time for several locations of interest.

The *Search and Rescue* (NAVSAR) model provides the capability to compute search recommendations and search-and-rescue effectiveness probabilities. The outputs are based upon ocean currents, wind, and search asset information. Upper-air data is used as input when a pilot ejection is involved.

The *MAD Operational Effectiveness* (MOE) program produces chart displays of the magnetic anomalies produced from geologic sources. These charts can aid the tactical planner in alerting him to areas of high geologic noise, which may affect the operational capabilities of the MAD equipment. The contours displayed indicate the maximum expected amplitude of the geologic noise (in nanoteslas) that will pass through the MAD system filters. The tactical planner uses this information to make the most effective use of the platforms equipped with MAD gear (ASQ-10, ASQ-81V). Aircraft platforms include the P-3, S-3, SH-2, SH-3 and SH-60/LAMPS MK III.

Acoustic Programs

The TESS Acoustic programs consist of Passive Acoustic Propagation Loss; Range-Independent Propagation Loss; Sensor Performance Prediction; Generalized Range-Dependent Acoustic Driver; Ambient Noise; and Tactical Oceanographic/Acoustic Spreadsheet.

The *Passive Acoustic Propagation Loss* (PPL) program computes signal propagation loss as a function of range dependence or independence for a given set of geometric, environmental, and sonar-dependent data within the area of interest.

The *Range-Independent Propagation Loss* program calculates transmission loss as a function of range (without regard to direction), frequency, source depth, and receiver depth. The calculations from this program are used in the prediction of sensor performance within a specified ocean-area of interest.

The *Generalized Range-Dependent Acoustic Driver* (GENRAD) is an environmental module designed to aid execution of the Navy Standard Range-Dependent passive propagation loss models (that is, Parabolic Equation and CZ Astral). GENRAD provides a means to position on-scene and historical sound speed profiles along a determined trackline(s) to allow range-dependent propagation loss model execution.

The *Sensor Performance Prediction* (SSP) model computes detection range predictions for

various sensor suites. Probability-of-detection ranges are calculated for direct path, convergence zone, and bottom bounce. Median detection ranges (MDR) are computed for various types of sonobouys. Graphic representations of the detection coverage of various platforms in a task force are provided, as well as detection coverage for sonobouys and counterdetection by hostile submarines with the NEWCON, FENIKS-M, and VICTOR III sonar suites.

The *Ambient Noise* (AN) model predicts noise levels resulting from shipping, surface wind, and residual sources. The use of confidence limits, seasonal corrections, and statistical parameters yields a prediction of the variation of ambient noise with distance and direction. Also, corrections for sound frequency and long period temporal variations of the noise are included.

The *Tactical Oceanographic/Acoustic Spreadsheet* (TOAS) module computes sensor prediction data using the platform/sensor data bases and the propagation loss model data bases. It requires very little operator input.

Message Composing Programs

The message composing module provides the capability to assemble and format bathythermograph, ASRAPC, and PHITAR messages.

Satellite Applications

The Satellite Applications section is designed to acquire, process, and display satellite data received from polar-orbiting and geostationary weather satellites. The section is divided into Satellite Ephemeris and Tracking, and Satellite Imagery Application routines.

SATELLITE EPHEMERIS AND TRACKING.—The Satellite Ephemeris and Tracking routine is composed of three separate programs; the Editor Orbital Satellite program; the Orbital Satellite Prediction program; and the Geostationary Satellite Prediction program.

The *Editor Orbital (EDORB) Satellite* program is used to enter, edit, or delete one-line CHARLEY ephemeris data strings. These elements are stored in the Orbital Element Set file for use in the *Orbital Satellite Prediction* program, which provides satellite-pass summaries consisting of the rise time, set time, pass duration, ship's position during the pass, and maximum elevation, for operator-selected satellites. Individual passes may be examined in detail for antenna-aiming and satellite-subpoint data at 1-minute intervals. In addition to the CHARLEY data, the operator must input the ship's track.

The *Geostationary Satellite Prediction* (GSAT) function provides antenna-aiming data based on operator-specified ship's position and bearing, along with the satellite longitude.

SATELLITE IMAGERY APPLICATIONS.—The Satellite Imagery Application programs consist of a TBUS Entry program; a Satellite Track and Schedule program; an Acquire program; an Earth Locate program; a Pathfinder program; and a Display program.

The *TBUS Entry* program uses the APT Predict *TBUS* message to create the epoch parameters and the satellite ephemeris files used to predict the orbits of the NOAA-series polar orbiting satellites. This program also computes the ascending node longitude and time for these satellites.

The *Satellite Track and Schedule* (ORBIT) program displays orbital paths of the NOAA satellites from existing ephemeris files. This program also displays the swath of Earth that will be covered by the satellite's sensors on each user-specified orbit. Tabular listings of satellite azimuth and elevation angles are also produced.

The *Acquire* program allows the operator to track, capture, store and display real-time satellite imagery data. The data is displayed in on-scene as it is received line by line. The operator has a limited ability to enhance the image as it is being displayed.

The *Earth Locate* (NAVIG) program corrects for inaccuracies due to the age of the *TBUS* data used in the Acquire program. It matches estimated locations of known "ground control points" (GCPs) retrieved, along with coastal points, from a permanent data base for areas corresponding to the image swath, to their actual locations on the image. In other words, it adjusts the latitude/longitude grid on the image (and in the data file) by matching identifiable geographic features with their actual latitude and longitude.

Pathfinder forms observed-oceanographic-frontal-path files and displays the best-guess locations for oceanographic fronts when an area is obscured by clouds. This program operates with the Gulf Stream, the Kuroshio, and the GIUK currents.

A *Display* (DOALL) program allows the operator to manipulate the image to determine the presence of various atmospheric and oceanographic phenomena. Color or grey-shade enhancements can be used to identify specific atmospheric/oceanographic features, to determine sea surface temperature gradients, and to analyze cloud-top temperatures and heights.

Briefing Support Program

The *Briefing Support* program allows the TESS user to assemble, package, and present data for use in mission planning and briefing. Upon display of any graphic or tabular data, the operator may print a hard copy. Without operator intervention, all displayed data will be maintained for 48 hours.

UNIT 4—LESSON 6

OPARS COMPUTER FLIGHT PLANS

OVERVIEW	OUTLINE
Define the term OPARS.	General information
Identify the standard information presented in OPARS CFPs.	OPARS CFP data arrangement
Identify the 11 OPARS CFP formats and identify which formats contain flight level winds and temperatures.	OPARS CFP formats
Interpret the information presented in the flight identification data.	Flight identification data
Interpret the aircraft fuel/time/weight summary data.	Aircraft fuel/time/weight summary
Interpret the en route data.	En route data

OPARS COMPUTER FLIGHT PLANS (CFPs)

Aerographer's Mates at our Naval Oceanography Command (NOC) Detachments and Facilities normally receive OPARS CFP requests from pilots, and format these requests in a computer-acceptable manner on their microcomputers (Z-120, Z-248, or Whisperwriter). The formatted requests are transmitted to FNOC via telephone modem. The completed CFP is transmitted back to the microcomputer terminal in the same manner, and passed to the pilot. Some aviation units operate their own terminals and send their requests directly to FNOC. OPARS CFPs may also be requested by Automated Defense Information Network (AUTODIN) message, with the completed CFP transmitted to the user and/or requester by message. This last method must be used when classified CFPs are required, since the telephone-modem method is not secure.

Learning Objective: Define the term OPARS.

OPARS is an acronym for the Navy's Optimum Path Aircraft Routing System program, operated by the Fleet Numerical Oceanography Center (FNOC), Monterey, California. The primary purpose of the program is to increase aircraft flying safety. Computer-calculated flight plans provide the pilot with detailed fuel usage information, based on the specific aircraft's design, cargo weight, and destination, as well as the forecast atmospheric winds, temperatures, and air densities. These computer flight plans (CFPs) inform the pilot of the proper amount of fuel required to reach his destination safely. The secondary purpose of the program is to conserve fuel. Based on the forecast meteorological conditions, the flight planning computer normally

will select the best routing and flight altitudes for an aircraft to use to reach the intended destination using the least amount of fuel. This option is defeated when the mission requires that a specific, detailed route and flight level be followed.

As a briefer you will be required to brief many flights for which OPARS CFPs have been requested. In addition to briefing the pilot about the information in the CFP, you will need to verify that the meterological data in the CFP is correct by comparing it to available charts. In order to do both tasks properly, you must be able to interpret the information on the OPARS CFPs. Detailed information on encoding OPARS CFP requests and decoding OPARS CFPs is available in the *OPARS Users Manual*, FLENUMOCEANCENINST 3710.1. Additional information about the 9KB format is available in *Optimum Path Aircraft Routing System (OPARS) C9B Aircraft Overwater Procedures*, FLENUMOCEANCENINST 3710.3. These manuals are provided to all authorized users of OPARS, along with the passwords and identification codes necessary to gain access to the system. In this lesson, you will learn how to interpret the information presented in the 11 different OPARS CFP formats.

To help you identify and interpret information in the CFPs, we have grouped different types of information together and "named" these groups of information. It is important that you keep in mind that although we are naming certain groups of information, these names are just a tool to help you identify different types of information. After you are able to interpret the information presented in the Flight Plans, you should remember these names only as a general classification of the type of data presented, and not as a specific name of a line or section of the OPARS CFPs.

Learning Objective: Identify the standard information presented in most of the OPARS CFP formats.

OPARS CFP DATA ARRANGEMENT

With the exception of 2 of the 11 OPARS CFP formats, the CFPs use the same overall format to present the different types of data. Figure 4-6-1 shows a typical OPARS CFP, in this case the most requested 3KB or Kneeboard 3 format. We have outlined the general types of data. All OPARS CFPs contain *Flight Identification* data, and all contain a *Fuel/Time/Weight Summary*. All but two of the formats, the ABB, or Abbreviated, format and the HOW, or How-goes-it, format, contain *en route data*. We will cover these types of information and the differences in the formats after we discuss the 11 formats that are available.

Learning Objective: Identify the 11 OPARS CFP formats and identify which formats contain flight level winds and flight level temperatures.

OPARS CFP FORMATS

OPARS currently uses 11 different formats that have been designed to suit the requirements of the different aviation communities supported by the program. The formats are listed below:

- ABB or Abbreviated format—a very short CFP format that contains only the flight identification data and the aircraft's fuel/time/weight summary. This format is used primarily for flight pre-planning to provide information on distance, fuel requirements, initial cruising flight level, and flying time to the destination. Although it provides a total wind factor for the entire flight, it does not contain any other en route data.

- HOW or How-goes-it—a format designed to provide a graphical display of fuel use versus distance traveled. This format does not contain flight level winds or temperatures. Like the ABB format, it does provide a fuel/time/weight summary and should only be used for flight pre-planning.

- 1KB or Kneeboard 1—a format designed for use with an aircrew kneeboard, a device used to hold information and which straps to a pilot's leg, just above the knee, so that the information is readily available during flight. This particular format provides both flight level winds and temperatures, and a wind drift correction, which the pilot may apply to the magnetic course to obtain a magnetic heading for the aircraft.

- 2KB or Kneeboard 2—a modification of the 1KB format which also provides flight level

FLIGHT PLAN FOR LT AVIATOR COMPUTED 1511Z
BASED UPON 8711220000 WEATHER DATA
LEG01 STANDARD KMRY TO KNZY 22 NOV 87
ACFT TYPE P3B99F5 DRAG:156 EFF:100

PLANNED FOR ETD 2300Z INITIAL CRUISE FLIGHT LEVEL 290

Flight Identification Data

	FUEL	TIME	DIST	ARRIVE	RAMP	LAND	CARGO	OPNLWT
POA	004970	1/10	0332	0010Z	086970	082000	000000	072000
ALT	...							
RES	010000	2/20						
TOT	014970	3/30						

FUEL BIAS: 661 DBIAS: 0 ABIAS 0 IBIAS: 0

Fuel/Time/Weight Summary

ROUTING USED FOR THIS LEG
KMRY .. AVE J1 LAX39 .. KNZY

Flight Identification Data

TO	FL	T/C	M/C	WIND	DFT	G/S	TAS	DIS	CUMD	DISR	ETE	CUMT	ETR	EFR
KMRY	0	000	***	00000	00	***	***	1	1	331	00/01	00/01	01/09	143
TOC	29	122	106	02559	R15	***	***	93	94	238	00/21	00/22	00/48	124
AVE	29	121	105	03055	R10	341	341	14	108	224	00/02	00/24	00/46	123
AVE42	29	145	129	03646	R08	357	341	42	150	182	00/07	00/31	00/39	118
REYES	29	145	129	04538	R07	348	340	30	180	152	00/05	00/36	00/34	115
LAX39	29	147	131	05034	R06	343	339	17	197	135	00/03	00/39	00/31	113
SDP	29	140	125	11023	R04	328	339	68	265	67	00/12	00/52	00/18	106
KNZY	0	140	126	13509	00	***	***	68	333	0	00/18	01/10	00/00	99

KMRY	N36353W121509	*TOC*	N35458W120131	AVE	N35388W119587
AVE42	N35044W119294	REYES	N34395W119081	LAX39	N34256W118571
SDP	N33337W118049	KNZY	N32420W117129		

TOC = TOP OF CLIMB
SDP = START OF DESCENT POINT

TOTAL WIND FACTOR 3KTS

En route Data

FL/FUEL/ETE 270/ 4900/ 1+09 250/ 5000/ 1+09 230/ 5100/ 1+10

Fuel/Time/Weight Summary

Figure 4-6-1.—A typical OPARS CFP outlining the three types of data common to OPARS CFP formats.

winds and temperatures. A magnetic heading, corrected for wind drift, is provided.

- 3KB or Kneeboard 3—a modified kneeboard format that provides flight level winds, but does not provide temperatures. Since flight level temperatures are used to manually calculate fuel burn rates for flight planning, and since fuel burn has already been calculated by the CFP, the omission of this data is not significant. A wind drift correction is provided for use with the true course and magnetic course for the pilot to calculate either true heading or magnetic heading.

- 4KB or Kneeboard 4—another modified kneeboard format, this one does not contain winds, temperatures, or drift corrections. A magnetic heading, corrected for wind drift, is provided to guide the aircraft.

- 5KB or Kneeboard 5—yet another modified kneeboard format, similar to the 3KB in that it contains flight level winds, omits temperatures, and contains a wind drift correction factor for the pilot to apply to the magnetic course to obtain a magnetic heading.

- STA or Standard format—a longer format than the kneeboards, it is not as cryptic; information is easier to interpret and better identified. Although it does not provide any flight-level winds or temperatures, a true heading corrected for wind drift is provided.

- TAC or Tactical format—the format allows some special options for use on tactical missions. This format contains flight-level winds and temperatures, as well as a magnetic heading corrected for wind drift.

- MAC or the USAF Military Airlift Command format—designed to be similar to one of the most frequently used USAF CFP outputs, it contains flight-level winds and temperature deviations, as well as magnetic headings corrected for wind drift.

- 9KB or Kneeboard 9—a format designed especially for the Navy's DC-9 and C9B overwater passenger flights, this format contains flight-level winds and magnetic headings corrected for wind drift, but does not contain flight-level temperatures.

NAVOCEANCOMINST 3140.14C, *Procedures Governing Flight Weather Briefings and Preparing DD form 175-1 and U.S. Navy Flight Forecast Folder*, allows the entry *OPARS* in the Flight Level Winds/Temperatures block of the Weather Briefing form, DD 175-1, if the information is actually provided in the OPARS CFP. When this information is not provided in the CFP or if the forecaster does not agree with the OPARS winds and temperatures, the winds and temperatures should be obtained from an alternate source and entered in the data block.

Learning Objective: Interpret the information presented in the flight identification data.

THE FLIGHT IDENTIFICATION DATA

The *flight identification data* is information that identifies the flight. Each leg of a multi-leg flight plan will begin with the flight identification data. During a pilot briefing, the identification data should be verified by the pilot to ensure that the plan is for the correct type of aircraft and that it is correct and complete for the pilot's mission. An incorrect aircraft type or routing may invalidate the OPARS CFP.

OPARS allows up to three legs per flight plan. A *leg* usually refers to a portion of a flight from takeoff to landing, but may refer to a portion of a flight to, from, or between air refueling points, or to, from, or between mission operating areas. An aircraft's *Flight* or *Mission* may consist of a single leg, which means that the first place the aircraft lands is the ultimate destination, or it may consist of several legs, which means there are several intermediate stops or landings that the aircraft must make before the ultimate destination is reached.

The flight identification data for each of the Kneeboard formats, the Abbreviated format, the How-goes-it format, and the Tactical format are identical. Look at this information in figure 4-6-1, the 3KB format. The first four printed lines, containing the pilot's name, the time the flight plan was computed, the meteorological data base used, the leg number, the departure and arrival

points, the date, and the aircraft type are mostly self explanatory. The aircraft type in this case begins with a designation you may be familiar with, *P3B*, but you may not recognize the additional designators that follow. The *99F5* identifies engine-fuel-use characteristics as identified by the pilot when the plan was requested. The *DRAG* and *EFF*iciency figures also are based on the pilot's request.

The fifth line contains the estimated time of departure (*ETD*) in ZULU time (UTC) and the initial cruising flight level in hundreds of feet.

The next six printed lines contain information on fuel use, flying times, and aircraft weights; this is the aircraft's fuel/time/weight summary. We will discuss this information later in the lesson.

The twelfth printed line is the statement *Routing used for this leg*, which means the routing summary follows on the next line. In this case, the routing summary is *KMRY . . AVE J1 LAX39 . . KNZY.*

- The four-letter identifiers such as *KMRY* and *KNZY*, are airfields.

- The three-letter identifiers such as *AVE*, are en route radio navigation aids (navaids). There are several different types of navaids: Non-directional Radio Beacon (NDB); Tactical Air Navigation (TACAN); VHF Omni-directional Range (VOR); VHF Omni-directional Range/Tactical Air Navigation (VORTAC); and Distance Measuring Equipment (DME). The navaids transmit coded radio pulses, which are received by the aircraft's radio navigation equipment, which shows the pilot the bearing and distance to the navaid transmitter.

- The two dots mean point-to-point routing was used for that portion of the flight (standard high- or low-level routes were not followed).

- The *J1* between *AVE* and *LAX39* means that Jetroute 1 was followed. Other jetroutes may be identified as J180, J299, etc.

- *LAX39* is a *Radial*. These are used in flight plans to indicate a distance from a navaid. In this case, the aircraft is to fly along the J1 jetroute (toward LAX) until it reaches a distance 39 nautical miles from LAX, then it is to depart the jetroute to fly a direct (point-to-point) route to KNZY.

- Another type of identifier you will see in the routing is a five-letter identifier such as *TRACI* or *REYES*. These are IFR reporting points. When flying an IFR flight plan, the pilot must contact the area Air Traffic Controller at these points.

NOTE

When briefing a flight using any of the OPARS CFPs, you must check the routing used for the flight. Any station briefing CFPs should have a large wall planning chart that shows the standard jetroutes, navaids, and reporting points. Once you familiarize yourself with the routing selected by OPARS, you may then determine the weather along the route and fill in the DD 175-1.

The MAC format is quite different. See table 4-6-1. It contains the statement *OPARS computer flight plan*, a flight plan identification number beginning with *CFPI*, for computer flight plan identification, and followed by, in this case, **2502232.0**.

The second line identifies the departure point, *KDEN*, the destination, *KNGZ*, the aircraft type, *C9BFNF*, the OPARS data base identification **OGB** (which means *OPARS Global Weather Database*) or **OCL** (which means *OPARS Climatological Database*), and a departure date/time window, usually 4 hours either side of the requested departure time, **7/08Z-16Z**.

The third line gives a summary of the routing used for the flight. This same type of routing summary is used with the other OPARS CFP formats but is usually found after the fuel/time/weight summary.

The next line states that the CFP is an optimized fuel plan, meaning that it is based on the best route and altitudes to save fuel. The next two lines are actually part of the aircraft fuel and weight summary, which is continued after the en route data section. We will cover those a little later.

Table 4-6-1.—MAC Format OPARS CFP Example

OPARS COMPUTER FLIGHT PLAN CFPI-2502

KDEN KNGZ C9BFNF *OGB* 7/08Z-

KDEN .. DEN J80 SCK .. KNGZ

OPTIMIZED FUEL PLAN

OPNLWT 65000 PAYLOAD 23767

DEP FUEL/TIME BIAS 500/0005 ARR FUEL/TIME BIAS 500/000

LOCATION	ALT	WIND	TAS	GS	ZD	ZT	TT	TDR	TC	MC
LAT LONG	TTR	B/O	TDEV							
STAPLETON INTL										
N39465 W104527	0023							831		
DEN	64	270/ 27	***	***	2	1	001	829	344	331
N39480 W104527	0222	0014	+07							
TOC/ LEVEL OFF	280	280/ 73	***	***	109	25	027	720	256	242
N38220 W107112	0157	0500	+13							
TRACI	280	285/ 72	435	370	63	10	037	657	256	242
N39071 W108305	0147	0060	+13							
GJT	280	290/ 72	434	372	14	2	039	643	255	240
N39036 W108475	0144	0062	+13							
MLF	310	300/ 61	449	392	202	31	110	441	258	242
N38216 W113008	0113	0094	+12							
ILC	310	300/ 51	446	398	65	10	120	376	264	248
N38150 W114236	0103	0103	+12							
OAL	310	305/ 28	445	413	160	23	143	216	265	247
N38002 W117462	0040	0124	+13							
TIOGA	310	320/ 27	443	424	78	11	154	138	267	250
N37560 W119256	0029	0134	+13							
BEGIN DESCENT	310	325/ 27	442	428	21	3	157	117	266	249
N37545 W119528	0026	0137	+13							
DUCKE	299	325/ 25	***	***	10	2	159	107	266	249
N37539 W120060	0024	0138	+14							
SCK	202	320/ 12	***	***	51	8	207	56	266	248
N37500 W121102	0016	0141	+16							
KNGZ	0	015/ 18	***	***	54	16	223	2	267	250
N37470 W122190	0000	0149	+03							

CFP ALT FWF −41 WF1 −40 WF2 −42 ENDURANCE 0326 TOGW 109

A1 KNUQ	ALT	TDEV	WIND	TAS	GS	ZD	AD	ZT	TO
	310	+14	345/ 27	441	468	26	26	003	

1-0223 013618	2-0059 006000	3-0322 019618	4-0003 00
5-0000 000000	6-0005 000500	7- 000000	8-0326 01
9- 001323	10- 021321	13- 000790	B/O 01

The one remaining format, the Standard format, has a flight identification data arrangement that is different from both the MAC format and the Kneeboard formats but very easy to understand since everything is spelled out. Table 4-6-2 shows the Standard format, with sections identified as *General Information*, *Flight Log*, and *Navigational Log*. These sections contain the aircraft's flight identification information.

Table 4-6-2.—Standard Format OPARS CFP Example

GENERAL INFORMATION

PILOT NAME: LT AVIATOR

AIRCRAFT TYPE: P3B99F5

AIRCRAFT EFFICIENCY INDEX: 100

FUEL TYPE: JP-5

BASED UPON 8711220000 WEATHER DATA

DEPARTURE DATE: 23 NOV 87 TIME: 0700Z

POINT OF DEPARTURE:	MONTEREY PENINSULA	KMRY
DESTINATION:	NORTH ISLAND NAS	KNZY

INTERMEDIATE STOPS:

NONE

FLIGHT ROUTING:	POD	POA
$R	MONTEREY PENINSULA	NORTH ISLAND NAS

INITIAL CRUISING ALTITUDE: FL290

ALTITUDE CHANGES EN ROUTE:

FL 8 KMRY

FL290 TOC

FL O KNZY

REMARKS:

NONE

LEG SUMMARIES:

LEG	POD	POA	ETD	ETA	ETE	FUEL	ALTNT
1	KMRY	KNZY	0700Z	0807Z	1/07	4805	---

ESTIMATED TIME ALOFT: 01 HRS 07 MIN

FLIGHT LOG

LEG01 STANDARD MONTEREY PENINSULA TO NORTH ISLAND NAS

ETD 0700Z ETA 0807Z FUEL CHANGE 4805 LBS CARGO 500 LBS

WEIGHTS: TAKEOFF 85805 LBS LANDING 81000 LBS

FUEL BIAS: 661 DBIAS: 0 ABIAS: 0 IBIAS:

ROUTING USED FOR THIS LEG

KMRY .. AVE J1 LAX .. KNZY

NAVIGATIONAL LOG

NAV	FREQ	HD	VAR	D	CUM	TAS	WF	GS	ETE	ETR	FF	FU	EFR
KMRY	0.0	000	***	1	1	***	000	***	00/01	01/07	*****	661	12143
TOC	0.0	107	16E	93	94	***	000	***	00/20	00/46	5399	1823	10319
AVE	117.1	111	16E	14	108	342	010	352	00/02	00/44	3606	146	10173
AVE42	*****	138	16E	42	150	341	032	373	00/07	00/37	3602	404	9768
REYES	*****	138	16E	30	180	341	027	368	00/05	00/32	3589	297	9471
LAX39	*****	141	15E	17	197	340	025	365	00/03	00/30	3580	162	9308
LAX	113.6	133	15E	39	236	340	014	354	00/07	00/23	3576	397	8911
SDP	0.0	135	15E	27	263	339	008	347	00/05	00/18	3564	274	8637
KNZY	0.0	140	13E	69	332	***	000	***	00/18	00/00	2100	642	7995

KMRY	N36353W121509	*TOC*	N35461W120137	AVE	N35388W11
AVE42	N35044W119294	REYES	N35395W119081	LAX39	N34256W11
LAX	N33560W118259	*SDP*	N33354W118055	KNZY	N32420W11

TIME ON GROUND: 00+00 HRS CARGO CHANGE: NONE FUEL ONLOAD: N

TOTAL WIND FACTOR 16 KTS

FL/FUEL/ETE 270/ 4800/ 1+08 250/ 5000/ 1+10 230/ 5100/

The only information in this section that may need explanation is some of the abbreviations used:

- *$R* under the Flight Routing title means *on and off standard jetroutes*. The flight will follow standard jetroutes only if they are near the best fuel-savings route.

- *POD* is point of departure.

- *POA* is point of arrival.

- *TOC* is top of climb.

- *ETD* is estimated time of departure.

- *ETA* is estimated time of arrival.

- *ETE* usually means estimated time en route between the points specified, so in this case (the two specified points are *POD* and *POA*), it means the length of the flight in hours and minutes. The last line of the General Information section repeats this information in plain language.

- *ALTNT* is the alternate airfield selected by the requester for the destination airfield.

In the Flight Log section, the leg number, departure point, destination, and departure and arrival times are given, along with weight and fuel information. The last line of data in this section is the routing summary.

The flight identification information we have just covered includes, at a minimum, basic information to identify the aircraft type, time and place of departure, destination, cruising flight level, and a routing summary.

Learning Objective: Interpret the aircraft fuel/time/weight summary data.

THE AIRCRAFT FUEL/TIME/WEIGHT SUMMARY

The *fuel use, time required, and weight summary* provides critical information to the pilot for the safe operation of the aircraft.

In the Kneeboard formats, Abbreviated format, How-goes-it format, and Tactical format, this information is presented in a nearly identical manner. Look at the information identified as Fuel/Time/Weight Summary data in figure 4-6-1. On line 6 the column headings *FUEL*, *TIME*, *DIST*, *ARRIVE*, *RAMP*, *LAND*, *CARGO*, and *OPNLWT* begin the fuel/time/weight summary data, and refer to the line headings, on printed lines 7, 8, 9, and 10, labeled *POA*, *ALT*, *RES*, and *TOT*.

POA means point of arrival of the flight—the intended destination. We can interpret the data under the column heads as follows:

FUEL—fuel required to start engines at the departure point and to taxi, take off, and fly to the destination.

TIME—the time, in hours and minutes, needed to reach the point of arrival.

DIST—Distance from departure point to the point of arrival, in nautical miles.

ARRIVE—the planned time of arrival at the POA, in UCT (ZULU) time.

RAMP—The weight of the aircraft as it sits on the parking ramp at the departure station, in pounds.

LAND—The weight of the aircraft, in pounds, as it touches down at the destination. The landing weight should be the RAMP weight minus the fuel used to taxi and take off minus the fuel used in flight. In the Tactical format, some or all of the cargo weight may also be subtracted from the RAMP weight. This would be used in the case where munitions are unloaded (on a target) in flight, or parachutists/parachute cargo are unloaded during the flight. This option may only be used on a *Mission leg*.

CARGO—The cargo weight/passenger weight at the arrival station, in pounds. This is normally the same as the cargo and passenger weight at the departure station.

OPNLWT—The operational weight of the aircraft (both at departure and arrival locations), in pounds. The operational weight of the aircraft includes the weight of the aircraft unfueled, the installed equipment, and the crew and crew baggage. Although this figure includes weights for engine lube oil, hydraulic fluids, and crew drinking water, it does not include any fuel weights. Operational weight of an aircraft usually doesn't change unless the aircraft is reconfigured or modified.

On line 8, *ALT* means alternate destination. If an alternate has been selected in the OPARS request, this line will contain entries for each column. The figures will be the differences that would occur between the intended destination and the alternate destination, such as the additional fuel required to reach the alternate from the intended destination, and the additional flying time required.

Line 9, *RES*, is the NATOPS-required reserve fuel as requested by the pilot, and the additional flying time the reserve fuel would allow.

Line 10, *TOT*, is the total fuel that should be on the aircraft at the departure ramp, in pounds, and the total flying time that that amount of fuel would allow. Normally this figure includes the NATOPS-required reserve fuel, the fuel required to start engines and to taxi and take off from the departure point, the fuel required during flight from the departure point to the intended destination, and the fuel required to reach an alternate.

OPARS bases the in-flight fuel consumption on the total fuel figure. The aircraft's actual fuel use may differ considerably if the crew over-fuels the aircraft. For instance, this flight requires 14,970 pounds of fuel. If at the departure point, the crew actually loads 30,000 pounds of fuel, the extra 15,030 of dead weight would require that the engines work harder to maintain speed, or the aircraft would fly slower. More fuel would be burned than calculated by OPARS, and the times would differ significantly. Thus, the Fuel Optimization feature of OPARS would be defeated.

The last line of this section, printed line 11, contains entries as follows:

FUEL BIAS—The OPARS-calculated figure for fuel used for engine start, taxi, and takeoff, in pounds.

DBIAS—(departure bias) The requester-entered figure for extra fuel that may be required during departure for such things as being held on the taxiway during heavy traffic or for local area departure routes that may require the pilot to take the aircraft off a direct routing to the first in-flight navaid or location.

ABIAS—(arrival bias) The requester-entered figure for extra fuel that may be required for in-flight holding patterns at the destination or to keep the engines running on the ramp during loading/unloading of passengers.

IBIAS—(icing bias) The requester-entered figure for extra fuel that may be necessary if in-flight airframe icing conditions are encountered.

One additional line of data that is used on all the Kneeboard formats, the Standard format, and the Tactical format and that should be considered as fuel-use summary information is the very last line of the CFPs. On figure 4-6-1, look at the last line of data, which begins *FL/FUEL/ETE*. This is the Alternate Flight Levels summary. It provides information on the overall fuel use and flight time for the aircraft if it were to fly at different flight levels than those actually selected. In the example, the data should be read from left to right as three groups of three pieces of data, with each group providing the alternate flight level (FL), the fuel required for the flight at that flight level, in pounds (FUEL), and the cumulative time for the flight at that level (ETE). You would interpret **270/ 4900/ 1+09** as follows: If flight level 270 (27,000 feet) were used, the aircraft would require 4,900 pounds of fuel and 1 hour 9 minutes to make the flight. In the example, information is also given for alternate flight levels 250 and 230.

In comparing this information to the actual planned flight level, fuel use, and cumulative time information given earlier in the summary, we can see that the best flight level for this particular flight would be 270 vice the planned 290. While a 1-minute difference in flying time and a 70-pound fuel use difference is barely significant, large differences in fuel use or required flight times should be pointed out to the pilot.

The MAC format uses a different type of fuel and time summary than any of the other OPARS formats. In table 4-6-1, the fuel and time summary appears as the last three printed lines of the CFP. The summary is composed of the figures labeled **1-** through **13-** and *B/O-*. Two columns of data follow each label: one for time, in hours and minutes, and the other for fuel weight, in pounds. Not all labels are used in all summaries, and some labels only have data entered in the fuel column. The summary section contains the following information after each label:

- 1- Cumulative en route time (hours and minutes) and fuel (pounds) for the flight.

- 2- Time allowed by the reserve fuel, and reserve fuel required for the flight.

- 3- Total flying time available from en route fuel and reserve fuel, and the total en route and reserve fuel (1 + 2).

● 4- Time necessary to reach the alternate or time required to conduct a missed approach, and fuel required to reach the alternate or to conduct a missed approach. (The greater of the two.)

● 5- Identified time which may be required for an arrival holding pattern (due to heavy traffic), and fuel required for an arrival holding pattern (similar to ABIAS).

● 6- Identified time necessary to conduct a non-direct approach at destination, and required fuel to conduct approach at destination (similar to ABIAS).

● 7- Extra fuel identified by the requester.

● 8- Total flying time allowed by take-off fuel, and total take-off fuel (3 + 4 + 5 + 6 + 7).

● 9- Start up and taxi fuel (similar to FUEL BIAS).

● 10- Required ramp fuel (the amount of fuel that must be loaded onboard the aircraft) (8 + 9).

● 11- and 12- USAF CFP entries not used in OPARS MAC format.

● 13- Required Over Destination fuel (the fuel that should be remaining in addition to the required reserve fuel when the aircraft arrives over the destination) (4 + 5 + 6).

● B/O- Total burn-off fuel (includes engine start, taxi, takeoff, en route, and approach and landing fuel.

For a specific type of aircraft, the fuel and weight summary provides the pilot with calculations of overall required fuel and time for the flight, based in the cargo weight for the flight leg.

Learning Objective: Interpret the en route data.

EN ROUTE DATA

The last type of data that the OPARS CFPs contain is *en route data*. In the majority of the formats, en route data consists of (1) a section of point locations and associated information at these points in the flight, which we will call *en route point details*; (2) a listing of the points used in the routing along with the latitude and longitude of each point, a *latitude/longitude list*; (3) a listing of OPARS-entered flight profile point abbreviations with an explanation, *flight profile points;* and (4) a *total wind factor* for the flight.

En route Point Details

Look again at figure 4-6-1, at the section identified as en route data. The en route point details begin with one or two lines of en route point locations, with associated navigation information, flight times and distances, and fuel usage information. The data contained in the columns in each line is identified with an abbreviation at the top of each column. The one or two lines of data are repeated for each point used in the routing. This section of the en route data which provides specified points and associated information is used in all of the CFP formats except the Abbreviated format, which does not contain any specific point data, and the How-goes-it format, which provides a graph of the en route location identifiers plotted on a scale of *Fuel remaining in the aircraft's tanks* (in pounds) versus *nautical miles traveled*. The specific information that is included in each format's en route point details section differs slightly, and is identified in table 4-6-3. Generally, this section of the en route data identifies specific points along the intended flight route, and provides specific aircraft performance information at those points.

In the Standard format this information is contained in the section called the Navigational Log.

The en route point details section of the Tactical format is very similar to the Kneeboard, Standard, and Military Airlift Command formats except blanks are left in the lines of data for pilot/navigator-entered comments, such as under the headings *ATA* (for actual time of arrival at the location), *AFU* (for actual fuel use to the point), and *AFR* (for actual fuel remaining).

Latitude/Longitude Listing

The CFP formats that do not provide latitude and longitude with each navigation point within the data lines of the en route point details section will provide a listing of the specific en route point identifiers and the associated latitude/longitude.

Table 4-6-3.—Data Presented in the En Route Point Details Section of the Various OPARS Formats

The abbreviations are used to identify column headings across the top of the route section. The letter/numeral combinations under each of the OPARS formats shows the location of each piece of data in row (up to 2) and column (up to 15) which are repeated for each point of the flight routing as follows:

1A	1B	1C	1D	1E	1F	1G	1H	1I	1J	1K	1L	1M	1N	1O
2A	2B	2C	2D	2E	2F	2G	2H	2I	2J	2K	2L	2M	2N	2O

DATA DESCRIPTION	ABBRE-VIATIONS USED	OPARS FORMATS								
		1KB	2KB	3KB	4KB	5KB	STA	TAC	MAC	9KB
Point locations: airfields, navaids, checkpoints, top of climb, begin decent, etc.	TO	1A		1A	1A	1A				1A
	CPT		1A							
	NAV						1A	1A		
	LOCATION								1A	
Points also identified by latitude/longitude in en route section	LAT/LONG		2B		2A			12H	2AB	12B
Points identified by latitude and longitude in summary at end of en route section	(none)	XX		XX		XX	XX			
Distance from last specified point (nmi)	DST	1B				1B				
	D						1E	2B		
	DIS			1I						1I
	ZD		1J						1G	
Flight Level **(thousands of feet)**	FL	1D		1B	1C	1D				1C
Flight level/flight altitude **(hundreds of feet)**	FL							1I		
	F/L		1B							
	ALT						1O		1C	
NAVAID frequency or TACAN channel	FREQ				1B		1B			
	CHAN							2A		
Outside Air	OAT	1E						1J		
Temperature (°C)	TMP		1C							
Temperature deviation (°C)	TDEV								2E	
Flight level winds (°true/knots)	WIND	1F	1D	1E		1E		2J	1D	1F
Wind factors between specified points (knots, [−] is head wind, no sign is tail wind)	WF						1H			
Total Wind Factor;	(none)	XX	XX	XX	XX	XX	XX	XX		XX
Wind factor for entire leg of flight (knots, [−] is head wind) in leg summary	FWF								XX	

Table 4-6-3.—Data Presented in the En Route Point Details Section of the Various OPARS Formats—Continued

DATA DESCRIPTION	ABBRE-VIATIONS USED	OPARS FORMATS								
		1KB	2KB	3KB	4KB	5KB	STA	TAC	MAC	9KB
True course: intended flight direction of aircraft (°true)	TC T/C		1E	1C				1K	1K	
True heading: direction nose of aircraft must point to compensate for wind drift (°true)	HD T/H		1F				1C			
Drift correction pilot must apply to MC or TC to compensate for wind drift. (°Right/°Left)	DFT	1G		1F		1F				
Magnetic course (°magnetic) to the specified point	MC M/C	1C		1D	1D	1C			1L	1D
Magnetic heading (°magnetic) to the specified point	MH M/H MHD		1G		1E			1B	1M	1E
Magnetic variation (°East/°West)	VAR						1D	2I		
True air speed (knots), not compensated for head- or tail winds	TAS	1H	1H	1H	1F	1G	1G	2K	1E	1H
Ground Speed-speed made good over the ground (knots)	G/S GS	1I	1I	1G	1G	1H	1I		1F	1G
Cumulative distance to this point (nmi)	CUMD CUM CD	1J	1K	1J		1I	1F			1J
Total distance remaining for the flight leg (nmi)	DISR TDR			1K	1J				1J	
Total time en route to this point (hours and minutes)	TT CUMT ETE			1M					1I	1K
Flying time between specified points (hours and minutes)	ETE ZT	1K	1L	1L	1H	1J	1J	1C	1G	
Time remaining to destination (hours and minutes)	ETR TTR	1L	1M	1N	1I	1K	1K	2C	2C	

Table 4-6-3.—Data Presented in the En Route Point Details Section of the Various OPARS Formats—Continued

DATA DESCRIPTION	ABBRE-VIATIONS USED	OPARS FORMATS								
		1KB	2KB	3KB	4KB	5KB	STA	TAC	MAC	9KB
Fuel (flow) use rate (pounds per hour)	F/F				1K	1L	1L			
Fuel used since last point (hundreds of pounds)	B/O EFU	1M	1N		1L			1E		
Fuel used since last point (pounds)	FU						1M			
Max allowable fuel use (hundreds of pounds)	M/BO									1M
Total fuel used (hundreds of pounds)	T/BO B/O	1N							2D	1L
Estimated fuel remaining (hundreds of pounds)	EFR		1O	1O	1M	1M	1N			1N

This listing usually immediately follows the en route point details section. Latitudes are preceded with either a *N*, for north latitude, or an *S*, for south latitude, while longitudes are preceded by an *E*, for east longitude, or a *W*, for west longitude. All latitudes and longitudes either in the Latitude/Longitude listing or in the en route point details listing are given in degrees, minutes, and tenths of minutes. For example, a longitude listed as *W179528* would mean 179 degrees, 52.8 minutes west longitude.

Flight Profile Points

In addition to selecting navaids and reporting points along an intended flight route, OPARS will select several points in the flight profile significant to aircraft performance and will identify these points with an abbreviation in the en route point details section. These OPARS-selected points are listed and identified in plain language near the end of the en route data section. In the example given in figure 4-6-1, two of these points are given: **TOC** and **SDP**. After the latitude/longitude listing, these points are identified as *Top of Climb* and *Start of Decent Point*. There are many other points that OPARS will select as significant points in the flight profile, but since those points are always explained within the CFP, we will not cover them.

Total Wind Factor

The total wind factor is given near the end of the en route data section of every OPARS CFP except for the MAC format. It is the average head wind or tail wind component of the winds that will effect the aircraft on a flight leg. A negative value such as *Total Wind Factor −69* means that the aircraft will receive, on the average, a 69-knot tail wind for that flight leg. A positive value would indicate an overall head wind. The wind factors are already included in all calculations of fuel burn and flight times.

In addition to the total wind factor, the 9KB format provides wind factors for the first half and second half of the leg.

The MAC format's total wind factor is identified on a line that starts with *CFP ALT*, which means *computer flight plan altitude information*. Wind factors follow the abbreviations on that line given as *FWF*, *WF1*, and *WF2*. These terms are slightly different from the other formats in both the meaning of the term and the abbreviations used. The wind factors are average wind factors for cruising flight level only, and do

not include climb winds, intermediate flight level winds, or decent winds. The *FWF* identifies the *Forecast Wind Factor*, or wind factor for the entire portion of the flight at cruising altitude, and *WF1* and *WF2* indicate wind factors for the first half and the second half of the flight at cruising altitude.

The en route data of OPARS CFPs provides the pilot specific information about the flight route and about the anticipated performance of the aircraft along the route.

SUMMARY

OPARS CFPs provide the pilot with valuable information that may be used to properly plan and conduct a mission safely. Three types of data are provided in the CFPs. Aircraft and flight identification information insures that the actual flight plan applies to the specific aircraft and mission that the pilot intends to fly. The fuel/time/weight summary provides information on the fuel and time requirements for the flight based on the cargo load. The en route data provides specific flight performance information at significant points along the flight route. While the 11 OPARS formats are tailored to contain specific details necessary for the different aviation communities, all are intended to improve flying safety and to conserve fuel.

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UNIT 5

ENVIRONMENTAL BRIEFINGS

FOREWORD

The term *environmental briefing*, for meteorological and oceanographic purposes, is defined as "A concise and direct presentation of factual environmental data that provides aircrews, commanders, or staff officers with an educated basis for decision-making."

As an Aerographer's Mate Second Class and above, you will be preparing and giving environmental briefings of all types. There are many variations of the types of briefings that may be required of you. They range from the individual pilot weather briefing to the more complex and detailed command and staff briefings.

In this unit, we will discuss briefing techniques in Lesson 1 and the types of briefings in Lesson 2.

UNIT 5—LESSON 1

BRIEFING TECHNIQUES

<u>OVERVIEW</u>

Recognize the principles of good public speaking and briefing and the various types of visual aids used in briefing.

<u>OUTLINE</u>

Presentation

Visual aids

BRIEFING TECHNIQUES

The environmental briefing is one of the most important tasks assigned to Aerographer's Mates. In many cases, the basic information supplied in these briefings determines whether a mission or a large-scale operation is executed as planned, or postponed, altered, or canceled. The manner in which this information is presented is considered to be of equal importance with the material contained in the briefing.

You should understand that the information you present assists those being briefed in clearly determining the effect of the environment on projected plans and operations. You are the authority on an extremely important element affecting operations, and therefore you must be confident, convincing, and positive.

Briefings are where you sell your services and yourself. Do a good job, and your credibility and that of our community is looked on favorably; do a poor job, and the reverse is true.

Learning Objective: Recognize the principles of good public speaking and briefing and the various types of visual aids used in briefing.

PRESENTATION

Effective briefing is an art. It requires alertness, poise, and good judgment. Whether the information you present is in oral, written, or pictorial form, you must be able to think on your feet. There will be times when you will have to come up with precise factual answers to questions that are difficult or even embarrassing. You should avoid verbal ambiguities, vagueness, or misplaced emphasis, which could easily convey a mental picture completely different from the one you have intended.

Some helpful briefing hints are as follows:

1. Strive for force and enthusiasm.
2. Practice the briefing beforehand, when possible, and make sure you have an orderly presentation.
3. Avoid technical meteorological and oceanographic terms. For example, use the word *high* instead of *anticyclone*.
4. Avoid ambiguous and vague terminology. The terms *about, probably, might*, etc., convey no useful information, but they do convey an impression of hedging or guessing.
5. Make the entire briefing a running narrative, and give your information in terms applicable to the situation.
6. Discuss only the important or essential details, and keep the briefing as simple as possible. Remember, it is the effect of environmental conditions on planned operations that is important.
7. Be brief. From 3 to 7 minutes is usually ample time to discuss environmental conditions.
8. Present the briefing in the second person. The material is being presented for and to an

audience and is not a mere recitation of an environmental situation or a map discussion.

9. Never apologize for any part of your presentation. Present the best available information. If your confidence in your information is limited, you may state so.

10. Finish briefings forcefully, with a definite closing statement, and always ask "Are there any questions?". Sometimes, information briefed is not clear to all those being briefed.

The hints given are merely restatements of the principles of good public speaking. Of course, not every briefing situation employs all of these hints. However, you should remember that no matter what type briefing you give, the material you are presenting must be heard and understood.

VISUAL AIDS

The primary purpose of visual aids is to enhance understanding. Visual aids, as used in environmental briefings, are pictorial and graphical representations portraying the information on which you are briefing. Just as the oral portion of a briefing must be heard, the visual aids must be seen. The size of the pictorial representation depends upon the farthest distance a person receiving the briefing is seated.

For an individual pilot briefing, drawn charts or facsimile charts are normally adequate. For command, operations, or staff briefings, a number of other aids may be employed.

Transparent Projection

Transparent projection in the form of transparencies or slides is one of the primary visual aids used in briefings. Transparencies are easily constructed using clear plastic and cardboard borders. Grease pencils and certain types of magic markers are used to mark on the plastic. The transparencies can be reused by simply wiping the plastic clean with a soft cloth or paper towel and acetone. Transparencies are projected onto a screen using an overhead projector.

Opaque Projections

Another type of visual aid is that of opaque projection. Opaque projection uses a device known as the opaque projector. A mirror and lens arrangement in the projector permits the projection of opaque materials such as charts and graphs.

Opaque projection requires a fully darkened room in order to show details and coloring satisfactorily.

You should have a basic familiarity with ordinary projection devices such as the transparent projector, opaque projector, and slide projectors.

Charts

The information displayed on briefing charts varies with the type of mission. The following information is a basic guide, bearing in mind that each situation must be resolved in terms of the information desired, the materials available, and the limitations of the briefing.

The following information should be used as a guide in preparing briefing charts:

1. Boundaries between land and water areas may be shaded lightly in blue on the water side and in brown on the land side. Entire land and water areas may be shaded if desired.
2. All printing should be in black. The date and time are indicated in the lower margin and should be in the same time zone as used in the briefing.
3. Indicate planned routes using solid brown lines with arrowheads. For convenience and clarity, the route may be divided into zones. When zones are used, each zone should be numbered.
4. Show pressure systems and fronts using conventional symbols. Projected movements may also be shown.
5. Draw a sufficient number of isobars to show relative intensity and distribution of pressure systems.
6. Delineate areas of fog, dust, haze, smoke, and similar restrictions to visibility. Shade these areas in red. Yellow or brown are the colors normally used to shade in such areas, but yellow is hard to see at a distance and brown is used to denote land-sea separation.
7. Indicate cold and warm air advection with blue and red arrows, respectively.
8. Shade in or stipple important cloud areas. Amounts, cloud types, and the heights of bases and tops above MSL may be printed in pertinent areas.
9. Indicate the location of precipitation and weather hazards (thunderstorms, turbulence, and icing) using the appropriate shading and symbology.

The following are some do's and don'ts on briefing from charts:

1. Use a pointer; however, refrain from imitating Zorro. Too much pointer movement is

very distracting. One method of assuring this is to place your pointer firmly on the chart in the area you are about to discuss. Only move the pointer when you are going to discuss another area.

2. Stand off to the side of the chart so that you do not block anyone's view.

3. Do not reach across your body with the pointer. Face your audience and point using the hand closest to the chart.

4. Do not talk to (brief) the chart; maintain eye contact with your audience.

SUMMARY

Environmental briefings are important from many points of view. They are where you sell your product and yourself. A good briefer is positive and forceful and has the ability to convey current and forecast environmental conditions in a concise, easy-to-understand manner. Do not hedge in your briefing; state the conditions exactly as you see them. Operational commanders count on Aerographer's Mates to provide them with the most up-to-date environmental information to assist them in their decision-making. No matter how good the information is that you are putting out, if your briefing carries with it a note of hesitancy or unsureness, it will fail to get the attention it deserves. One way to maintain attention at briefings is through the use of visual aids. Transparencies, slides, opaque projections, and enhanced weather charts all enhance briefings.

UNIT 5—LESSON 2

ENVIRONMENTAL BRIEFINGS FOR NAVAL OPERATIONS

OVERVIEW

Identify the type of briefing most often given by Aerographer's Mates and ways used to shorten and enhance these briefings.

Differentiate between DD Form 175 and DD Form 175-1.

Describe the contents of DD Form 175-1, the correct procedures for completing each block, and the proper distribution of the completed form.

Describe the contents of the Navy Flight Forecast Folder.

Identify the criteria that must be met before an Aerographer's Mate can work up flight weather briefing forms and conduct flight weather briefings.

Identify visual and instrument flight rules and explain the importance of debriefing pilots and aircrews.

Define weather synopsis.

List the elements of importance in route planning, surface, submarine, and helicopter operations.

Explain the importance of a special evolution/briefing checklist and how one is developed.

OUTLINE

- Flight weather briefing
  - Briefing aids
  - DD Form 175
  - DD Form 175-1
  - Flight forecast folder
  - Flight weather briefers
- Navy flight rules
- Debriefing pilots
- Staff briefings
  - Weather synopsis
  - Special Evolution and briefing checklist
- Operations briefings
  - Surface operations
  - Submarine operations
  - Helicopter operations

ENVIRONMENTAL BRIEFINGS FOR NAVAL OPERATIONS

Environmental briefings may vary considerably in content and scope. They range from briefing an individual pilot for a short flight, to the more elaborate planning briefings conducted for high ranking naval officers and their staffs. Between these extremes there are as many types of environmental briefings as there are varieties of military operations. Included in this lesson are some general guidelines for some of the different types of briefings.

Learning Objective: Identify the type of briefing most often given by Aerographer's Mates, and ways to shorten and enhance these briefings.

FLIGHT WEATHER BRIEFING

The flight weather briefing is by far the most common type of briefing provided by AGs. At an average air station it is not uncommon for AGs to make 300 to 900 briefings per month. Because of the high number of briefings given at many stations and the variety of problems presented by different flight plans, briefers must impart all their weather data quickly and concisely.

The flight weather briefer is responsible for giving a pilot a complete description of existing and expected weather along a planned route of flight and at any terminals of interest. Definite statements must be made regarding cloud bases and tops, the freezing level, icing zones, turbulence, winds, thunderstorms, and fronts. Also, let pilots know of any possible variations in the weather so they can plan their flights accordingly.

Since each flight presents its own peculiar problems in planning and weather briefing, it is not possible to establish a standard briefing procedure. However, there is a definite sequence of thought you should follow when briefing pilots.

1. Briefly discuss the synoptic situation as it relates to the planned route of flight, and give a brief description of the current weather along the route, using selected observations along or near the route.
2. Briefly state forecast trends of enroute weather; identify significant changes to current conditions and the time they are expected to occur. Emphasize those areas in which severe weather warnings are in effect or forecast.
3. Briefly state expected weather changes at each scheduled destination and "alternate" airfield, relating significant forecast changes and the expected time of their occurrence.

NOTE

An "alternate" is an additional airfield selected by a pilot as a backup landing site when forecast weather conditions are such that landing at the primary landing field may be impossible.

4. Point out possible alternate routes, as may be appropriate, and discuss all possible changes in the weather along each planned route. Answer any specific questions posed by a pilot.

Experience has also provided us with a proven method of shortening the time spent in conducting many flight briefings: CONSIDERABLE TIME CAN BE SAVED BY KNOWING THE CURRENT WEATHER CONDITIONS ALONG THOSE ROUTES COMMONLY FLOWN FROM YOUR STATION.

Briefing Aids

There are many aids that are used in briefing pilots on current and expected weather during their flights. Depending on the type of flight and briefing time constraints, any number of briefing aids might be used. The following are but a few:

- Flight weather briefing form (DD Form 175-1)
- Latest hourly weather sequences
- Terminal forecasts for destinations and alternates
- Navy flight forecast folder
- Pilot and radar reports
- Latest synoptic chart
- Latest upper-air chart(s) for the applicable flight level(s)
- Latest satellite picture over the area of flight
- An OPARS flight plan

These aids enhance the overall effectiveness of flight weather briefings.

Learning Objective: Differentiate between the DD Form 175 and the DD Form 175-1.

Navy Flight Plan (DD Form 175)

Pilots are required to file a Navy flight plan, DD Form 175, for each flight. One of the many preflight requirements listed on DD Form 175 is a check of the current and forecast weather (1) for the point of departure at takeoff, (2) enroute, and (3) at all scheduled destinations and alternates. To assist pilots in completing DD Form 175, AGs complete a DD Form 175-1. See figure 5-2-1.

FLIGHT WEATHER BRIEFING

PART I - MISSION / TAKEOFF DATA

DATE	ACFT TYPE/NO.	DEP PT/ETD	RUNWAY TEMP	DEWPOINT	TEMP DEV	PRESSURE ALT	DENSITY ALT
		Z	°F/C	°F/C	°C	FT	FT

SFC WIND	CLIMB WINDS	LOCAL WEA WRNG/MET WATCH ADV	RCR
M T			

REMARKS/TAKEOFF ALTN FCST

PART II - ENROUTE DATA

FLT LEVEL	FLT LEVEL WINDS/TEMP

CLOUDS AT FLT LEVEL ☐ YES ☐ NO ☐ IN AND OUT

MINIMUM VISIBILITY AT FLT LEVEL OUTSIDE CLOUDS MILES DUE TO ☐ SMOKE ☐ DUST ☐ HAZE ☐ FOG ☐ PRECIPITATION ☐ NO OBSTRUCTION

MINIMUM CEILING	LOCATION	MAXIMUM CLOUDS TOPS	LOCATION	MINIMUM FREEZING LEVEL	LOCATION
FT AGL		FT MSL		FT MSL	

THUNDERSTORMS	TURBULENCE			ICING				PRECIPITATION			
MWA/WW NO	CAT ADVISORY Z			NONE				NONE			
☐ NONE ☐ AREA ☐ LINE	NONE	IN CLEAR	IN CLOUD		RIME	MIXED	CLEAR		DRIZ	RAIN	SNOW	SLEET
☐ ISOLATED 1-2%	LIGHT			TRACE				LT				
☐ FEW 3-15%	MOD			LIGHT				MOD				
☐ SCATTERED 16-45%	SVR			MOD				HVY				
☐ NUMEROUS - MORE THAN 45%	EXTREME			SVR				SHWRS				
HAIL, SVR, TURB, SEVERE, ICING, PRECIPITATION AND LIGHTNING EXPECTED IN AND NEAR TSTMS	LEVELS			LEVELS				FRZG				
LOCATION	LOCATION			LOCATION				LOCATION				

PART III - TERMINAL FORECASTS

AIRDROME	CLOUD LAYERS	VSBY/WEA	SFC WIND	ALTIMETER	VALID TIME
DEST/ALTN				INS	Z TO Z
DEST/ALTN				INS	Z TO Z
DEST/ALTN				INS	Z TO Z

PART IV - COMMENTS/REMARKS

BRIEFED ON LATEST RCR FOR DESTN AND ALTN ☐ YES ☐ NOT AVAILABLE | REQUEST PIREP AT

PART V - BRIEFING RECORD

WEA BRIEFED	FLIMSY BRIEFING NO	FORECASTER'S SIGNATURE OR INITIALS
Z		

VOID TIME	EXTENDED TO	WEA REBRIEFED AT	FORECASTER'S INIT	NAME OF PERSON RECEIVING BRIEFING
Z	Z	Z		

DD Form 175-1, FEB 87 *Previous edition may be used*

Figure 5-2-1.—DD Form 175-1, Flight Weather Briefing Form.

Learning Objective: Describe the contents of the DD Form 175-1, the correct procedures for completing each block, and the proper distribution of the completed form.

Flight Weather Briefing Form (DD Form 175-1)

The flight weather briefing form, DD Form 175-1, provides a comprehensive record of weather flight planning information for pilots and flight clearance authorities. This form should be completed with the utmost diligence and care in accordance with the policies set forth in COMNAVOCEANINST 3140.14.

A DD Form 175-1, or a locally manufactured form, is completed for all flights conducted in accordance with instrument flight rules (IFR). Locally manufactured forms are acceptable as long as they include all the information contained

on the DD Form 175-1. All entries in either case must be neat and legible.

If you refer back to figure 5-2-1, you will see that the DD Form 175-1 is made up of five parts, as follows:

Part I	Mission/Takeoff Data
Part II	Enroute Data
Part III	Terminal Forecasts
Part IV	Comments/Remarks
Part V	Briefing Record

The procedures for completing each of the five parts are contained in Appendix II.

FORM DISTRIBUTION AND RETENTION.— For in-person (over-the-counter) briefings, the pilot receiving the brief gets the original (top copy) of the DD Form 175-1, and the issuing activity retains the carbon copy. For autographic briefings, the briefing activity retains the original.

NOTE

Autowriters (automatic writing machines) connect weather offices with squadrons. The forecaster writes the briefing data down on the autowriter, and it is automatically copied on the remote autowriter. With autowriters, pilots can receive their copy of the brief without going to the weather office.

All activities issuing flight weather briefings must retain a copy of all briefings for at least 1 year.

Learning Objective: Describe the contents of the Navy Flight Forecast Folder.

Flight Weather Forecast Folder

A flight weather forecast folder is normally requested by pilots whenever flights are scheduled to transit large continental or oceanic areas.

CONTENTS.—As a minimum, the following products are included in the folder:

- DD Form 175-1
- HWD (horizontal weather depiction) chart
- Upper winds chart for proposed flight level(s)

Other products that may be requested and/or included are (1) a USN or USAF computer flight plan, (2) a ditch heading chart, (3) a predicted altimeter setting chart, and (4) any miscellaneous charts tailored for specific needs.

CHART PREPARATION.—Use ONLY black or dark blue pens/pencils when preparing charts; pilots and flight crews have difficulty seeing or reading other colors during nighttime flights. Also, use the symbology found on page 2 of the folder. Place the following legend on all charts in a conspicuous place:

TITLE OF CHART

VALID TIME

STATION IDENTIFIER

FLIGHT FORECAST FOLDER NUMBER (sequential by month)

RECORDS.—The issuing activity maintains a record of all flight forecast folders issued. The record is retained on board for 1 year in accordance with SECNAVINST 5212.5. Include the following information:

- Month and sequential number of the folder
- Valid time and source of all charts included in the folder
- Flimsy briefing number of the DD Form 175-1

HWD CHART.—This chart is basically a strip chart containing operationally significant weather data. The basic chart, or charts, may be prescribed by individual activities. Whenever possible, use the charts listed in Part I, Volume II, of the *DMA Catalog of Maps, Charts, and Related Products*. See figure 5-2-2.

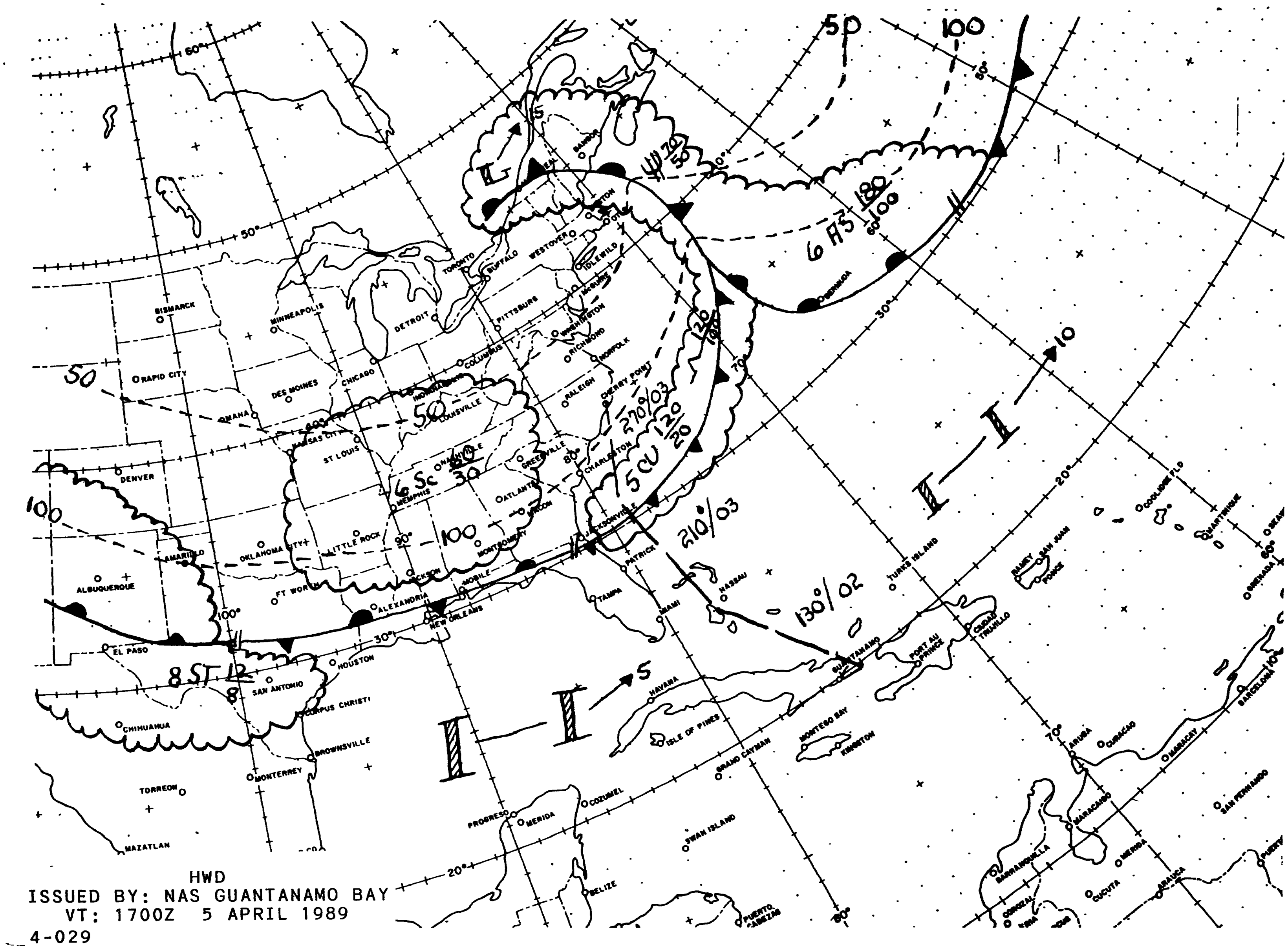

Figure 5-2-2.—Horizontal Weather Depiction Chart.

Size.—The overall size of the chart should be kept to a minimum; normally, the width should not exceed 8 inches.

Valid Time.—The valid time of HWD charts is dependent on a number of factors: (1) if HWDs are prepared in advance to meet everyday support requirements, use the 12-hour prognostic charts verifying at synoptic times, that is, 0000Z or 1200Z; (2) if a flight route requires a more tailored HWD, it should verify at the mid-time of the flight; and (3) if the request is short-fused (normally less than 2 hours' preparation time), use of centrally prepared charts verifying at the synoptic time closest to the mid-time of the flight is acceptable.

Flight Level.—Depict the atmospheric conditions from the surface to a minimum of 5,000 feet above the proposed flight level (higher if requested) along the entire route of flight.

Required Entries.—The following are required entries on HWD charts:

1. Areas of five-eights or more cloudiness; coverage is in OKTAS (eights) and includes the bases and tops of all cloud areas/types.
2. All areas of CB and TCU; coverage is in eights, and bases and tops are included.
3. Height of freezing level above MSL.
4. Fronts and pressure centers, including their direction and movement.
5. Significant weather and obstructions to vision.
6. Hazards to flight (icing, turbulence, etc.).
7. Proposed route of flight. If the flight route is classified, the entire folder is classified accordingly.

Miscellaneous Entries.—Miscellaneous chart entries are any additional entries deemed appropriate by the forecaster.

UPPER WIND CHART.—Prepare this chart from forecast data verifying near the mid-time of the flight.

COMPUTER FLIGHT PLAN.—When available, include a copy of the computer flight plan for the proposed route.

DITCH HEADING CHART.—A plot of the point values of predicted ditch headings (degrees magnetic) is included for all overwater flights. Ensure the chart is clearly annotated to indicate magnetic headings, vice true headings.

PREDICTED ALTIMETER SETTING CHART.—A plot of the point values of predicted altimeter settings is provided for all overwater flights operating at 1,500 feet or below, or when requested.

MISCELLANEOUS CHARTS.—Any other charts deemed operationally important to the flight may be included in the folder. Such charts may include constant-pressure charts, streamline charts, SST charts, etc.

Learning Objective: Identify the criteria that must be met before an Aerographer's Mate can work up flight weather briefing forms and conduct flight weather briefings.

Flight Weather Briefers

Flight weather briefings are conducted by those personnel who possess written authorization to conduct such briefings. The authorization must be signed by the commanding officer, officer in charge, or chief petty officer in charge. Normally, briefers are meteorological/oceanographic forecasters who have satisfied one of the following requirements:

1. Successfully completed the AG C-1 School
2. Earned a degree in meteorology from an accredited university
3. Successfully completed the meteorology course at the USN Postgraduate School
4. Qualified as a USAF or NWS weather forecaster

Flight weather briefers must also demonstrate proficiency in briefing and forecasting to the satisfaction of the granting authority; be familiar with current International Civil Aviation Organization (ICAO) regulations and Navy directives pertaining to aircraft operations; and be indoctrinated in local operations, procedures, and environmental phenomena.

Normally a FORECASTER completes the DD Form 175-1 for all briefings conducted in person and all autographic briefings. When briefings are delivered over voice circuits or via weathervision, both the pilot and forecaster complete the form.

NOTE

Aerographer's Mates who are NOT qualified forecasters may also complete the DD Form 175-1 and conduct flight weather briefings. However, there is one major stipulation: A QUALIFIED FORECASTER MUST APPROVE AND SIGN THE DD FORM 175-1 BEFORE THE INFORMATION IS BRIEFED.

Learning Objective: Identify visual and instrument flight rules and explain the importance of debriefing pilots and aircrews.

NAVY FLIGHT RULES

Specific rules and regulations are set forth for the safety of aircraft operations. Visual Flight Rules (VFR) and Instrument Flight Rules (IFR) are taken from OPNAVINST 3710.7. The flight rules that pertain to weather prescribe the minimum acceptable weather conditions for VFR and IFR flights. If these minimum conditions cannot be met, the flight clearance will not normally be given. The weather minimums are designed to give pilots enough time and space to avoid mid-air collisions during takeoff, enroute, and during approach and descent.

Visual Flight Rules

Visibility and cloud clearance minimums for VFR flights are dependent on whether the flight is within or outside controlled airspace. Controlled airspaces are those areas in which some or all aircraft may be subject to air traffic control. Figure 5-2-3 lists the basic VFR minimums applicable to flights within or outside controlled airspace. Additional VFR weather minimums are as follows:

1. At an airfield of departure, within the "control zone" the distance between the surface and the lowest "broken" or "overcast" cloud layer (ceiling) must be at least 1,000 feet. However, some airfields require that the ceiling be greater than 1,000 feet. At those airfields requiring a higher ceiling, pilots are cleared using the higher, more stringent minimum. The DOD Flight Information Publication (IFR Supplement) lists IFR ceiling requirements in the remarks section on each airfield.

NOTE

A "control zone" normally refers to a circular area around an airport (5-mile radius) and any extensions necessary to include instrument approach and departure paths.

ALTITUDE	VISIBILITY	DISTANCE FROM CLOUDS
Below 10,000 feet MSL		
Within controlled airspace	3 statute miles	500 feet below 1,000 feet above 2,000 feet horizontal
Outside controlled airspace	1 statute mile	Same as above or clear of clouds below 1,200 feet AGL
At or above 10,000 feet MSL	5 statute miles	1,000 feet below 1,000 feet above 1 statute mile horizontally

Figure 5-2-3.—Basic VFR Flight Minimums.

2. The lowest broken or overcast cloud layer at the destination must be forecast to remain at or above 1,000 feet or the prescribed published VFR minimum for the period 1 hour before and 1 hour after the aircraft's estimated time of arrival (ETA). If the prescribed minimum is higher than 1,000 feet, it is the pilot's responsibility to let you know this during the briefing.

3. The visibility at the destination must be 3 miles or more at the time of departure and be forecast to remain 3 miles or more for the period 1 hour before and 1 hour after the ETA.

4. The VFR minimums for helicopters differ from those for fixed-wing aircraft. VFR minimums for helicopters are ceiling 500 feet and visibility 1 mile.

Instrument Flight Rules

Pilots are required to file for an IFR clearance anytime weather conditions are forecast to be less than the VFR minimums.

TAKEOFF MINIMUMS.—Takeoff minimums are based on the lowest published landing minimums at the point of departure. The landing minimums are used as takeoff minimums, because in the event of an emergency shortly after takeoff, the pilot may have to return to the airfield.

INSTRUMENT RATINGS.—Navy pilots are instrument rated as either "standard" or "special" depending on their flight qualifications and experience. For pilots holding a "standard" instrument rating, the ceiling and visibility must be at least 300 feet and 1 mile, respectively, before they are permitted to take off. However, if the airfield has an approved precision approach radar and the published landing minimums are less than 300 feet and 1 mile, takeoff may be authorized based on the precision approach minimums. In NO case can a "standard" card pilot take off when the ceiling is less than 200 feet, visibility is less than one-half statute mile, or the runway visual range is less than 2,400 feet. For pilots holding the "special" instrument rating, takeoff minimums DO NOT apply.

DEBRIEFING PILOTS

Normally, weather debriefings consist of interrogation of pilots to determine the weather encountered during flights or missions. Pilots and aircrews can usually provide the most up-to-date information on actual route and/or target weather.

Information gained at debriefings provides a practical means of verifying the preflight forecast, and may be of considerable value in amending the forecast for later flights using the same route and/or going into the same area.

You have to impress on pilots and aircrews the value of the weather information they can furnish. If they can supply the exact time, place, and altitude of each observation, the information is much more valuable. The flight weather information is normally written on flight forecast folders, flight cross sections, in-flight report forms, or flight checklists.

Learning Objective: Explain how staff briefings differ from pilot weather briefings. Define weather synopses and explain how they are incorporated into briefings.

STAFF BRIEFINGS

Staff briefings are tailored to accommodate task-force commanders and district flag officers and their staffs. Staff briefings consist of many different briefers briefing on a multitude of subjects. More often than not, environmental conditions get briefed first and are presented by the environmental officer or the senior aerographer, usually the leading chief. However, there are times and situations when junior personnel conduct the environmental portion of these briefings. Mobile environmental team members at the E-5 and E-6 level are prime examples. They are called upon to brief the commander and staff with whom they are deployed.

The staff briefing is not as detailed as a flight or mission briefing; however, it is greater in scope. This is due to the size of the area and the various types of naval operations for which the commander has responsibility.

Weather Synopsis

Staff briefings, as well as most other briefings, are begun with the meteorologist/oceanographer giving a synopsis of the weather. A weather synopsis is a brief statement on the location and movement of pressure systems and fronts over the

region/area of interest. An example of a weather synopsis for the eastern United States is as follows:

> A low-pressure system centered over central Connecticut is moving east-northeast at 15 knots. A cold front extends south-southwest from this low to northwest Florida. The front is quasi-stationary from northwest Florida to Louisiana. Warm, moist tropical air is overriding the stationary front, causing considerable cloudiness and intermittent rain in this area. This condition is expected to exist during the next 36 hours. High pressure centered over Kansas is moving east at 10 knots and dominates the weather picture in the midwest.

OPERATIONS BRIEFINGS

Only after obtaining a comprehensive understanding of a planned operation should you prepare the weather briefing for the operation. Many lives and much costly equipment are generally involved; therefore, preparation of the brief cannot be haphazard in nature; compile as much data as possible and deliberately detail your briefing to the operation. The success or failure of an operation is often attributable, either entirely or in part, to the value of the environmental information given to the operational commander.

Learning Objective: List the elements of importance in route planning, surface, submarine, and helicopter operations.

Route Planning

Task-group commanders and COs desire long-range forecasts for route planning, to avoid bad weather and/or sea conditions. Today, wide use is made of Optimum Track Ship Routing (OTSR) services provided by Oceanography Centers. OTSR personnel use the latest long-range forecasts in conjunction with climatic data to recommend the best route on which to begin a transit.

Even with the popularity of OTSR, meteorology/oceanography officers aboard carriers and other ships with OA divisions normally compile climatic data and brief the officer in tactical command (OTC) and his staff, the CO, XO, operations officer, navigator, and other department heads before embarking on any extended cruise.

Surface Operations

Environmental briefings for surface ship operations vary considerably, depending upon the type(s) of ships and the mission being undertaken. Remember, you must be aware of all phases of an operation in order to evaluate and comment on how environmental conditions will influence the operation.

Elements of interest in operations briefings vary depending on the operation being undertaken. You should consider the following elements when preparing an operations brief for surface ships:

<u>Tropical cyclones (typhoons/hurricanes)</u>—Make a special effort to keep a track chart on these storms. COs are very aware of the danger they present and want as much advance notice as possible on their development and movement. Even though Oceanography Centers keep all ships advised of the location, intensity, and forecast movement of these storms through warnings and advisories, do not let these messages lull you into a false sense of security. Remember, the on-scene meteorologist/oceanographer or leading aerographer is responsible for keeping everyone informed about these storms. That person will often be asked to make a recommendation on what course of action the ship should take to avoid or lessen the effects of these storms.

<u>Sea conditions and wind speeds as related to the development of seas</u>—These are important items for most ships, because winds and seas affect so many surface operations.

<u>Visibility</u>—This element is of utmost importance to the safety of a ship. It can also control a ship's speed of advance (SOA). For example, if an extensive fog bank is expected to be encountered enroute, the CO may desire to increase the ship's SOA while visibility is good. In port, sailing times may have to be altered if fog is expected at the time of departure.

<u>Weather and obstructions to vision</u>—These items cover a multitude of possibilities in the realm of operations. Rain, snow, freezing precipitation,

etc., can all affect certain operations. If the bosun has scheduled topside painting and rain is in the forecast, you might be wise to inform the bosun. Of greater importance, the weapons officer should be briefed on forecast precipitation. This brief could stop the planned loading of missiles that are adversely affected by precipitation.

Cloud coverage and ceilings—These are important primarily to flight operations. However, in time of war it may be desirable to conduct surface operations beneath heavy cloud cover to lessen the chances of detection from the air. The use of fronts and squalls to avoid detection was common in World War II.

Radar and sonar conditions—The effect of the environment on these systems is extremely important. COs want to know the effect of the environment on their ship's systems and the systems of their adversaries. This information can be obtained using on-scene data in conjunction with computer programs, or it may be requested from the Fleet Numerical Oceanography Center.

Air temperature and sea temperature—These two elements are highly important in areas of cold-weather operations. When air temperatures dip below freezing, an accumulation of ice topside can seriously affect a ship's stability and endanger the lives of personnel. Of importance in times of war, a ship coated with ice is easier to see than one that isn't ice coated. Ice on a flight deck is extremely hazardous as has already been mentioned in a previous lesson.

Sea ice and drift ice—Both types of ice can be a hazard to navigation. When operating in polar climates, be sure to brief the distance to all known ice edges and drifting ice. Information on ice edges, bergs, etc., is available from the Naval Polar Oceanography Center.

Chill factor—Anytime personnel are working outdoors in near- or below-freezing temperatures, the wind becomes an added factor in how long personnel can safely remain outside without suffering from exposure. At sea, owing to the ship's SOA, the added wind across the deck must be taken into consideration. This information should always be briefed so that personnel may be advised on the type of clothing they should wear.

Learning Objective: Explain the importance of a special evolutions/briefing checklist, and how one is developed.

Special Evolutions/Briefing Checklist

Special evolutions take place aboard ship when certain weather occurs. You should be familiar with these evolutions and the officers responsible for initiating required actions. A checklist should be prepared listing the various environmental conditions and the individuals that need to be briefed in the event of their occurrence. Some examples of evolutions are shown on an abbreviated checklist as follows:

Evolution	Contact Point
Thunderstorms and heavy rains	Gunnery officer
Obstructions to vision	OOD
Freezing temperatures	Engineering officer

The development of a comprehensive checklist requires that all department heads be contacted. All too often we forget that we are aboard ships to provide a service. You should let people know who you are and what you can provide, then ask what you might be able to provide to help them. You might be amazed at what you find out, but more importantly, they can find out what you can provide to help them.

Submarine Operations

As far as subsurface operations are concerned, naval oceanography now plays a vital part in both operational and material activities. The following paragraphs contain a sampling of information of interest to submariners.

SOUND CONDITIONS.—Knowledge of sound conditions makes it possible to use sonar gear more effectively, and sound conditions are a factor in deciding the most effective tactical deployment depth for a submarine. Sound conditions are also important during diving operations when operating among enemy ships that may be maintaining a listening watch.

TEMPERATURE AND SALINITY PROFILES.—Knowledge of the subsurface distribution of temperature and salinity improves the planning of submarine diving operations and to a considerable degree affects the choice of offensive and evasive maneuvers. To change depth efficiently takes an appreciable amount of time to flood or pump the required amount of water. In time of war, a delay of a few minutes, caused by faulty judgment as to the correct ballast change, may prove costly.

WATER MASSES.—Brief on the water masses that will be encountered and the effects they will have on operations.

CURRENTS.—Brief on all ocean currents. Currents can be used to speed up transits and to avoid sonar detection.

EDDIES.—The latest location and movement of cold and warm eddies can be used by submariners in planning tactical maneuvers and operations.

Helicopter Operations

Helicopter pilots are thoroughly familiar with the flight characteristics of their craft and the effect of meteorological elements on their craft. The elements of interest to helicopter pilots follow.

WIND.—Wind speed, in combination with blade rpm and the forward speed of a helicopter, is critical to rotor blade efficiency and flight safety. Wind direction is important from a navigational aspect.

DENSITY AND PRESSURE ALTITUDE.—Air density and the pressure exerted by the atmosphere control the load capacity/operating ceiling of helicopters. At sea these computations are extremely important, because there is little room for error once a helo lifts off the deck of a ship.

FREEZING AND FROZEN PRECIPITATION.—Freezing and frozen precipitation are extremely dangerous. Accumulations of snow and ice on helicopters prevents them from taking off. All snow and ice must be removed prior to takeoff.

SURFACE AIR TEMPERATURE.—Surface temperatures control the type of lubrication used in certain helicopter systems.

In addition to the above elements, there are the normal forecast elements of ceiling, sky, and flight visibility. Under bad weather conditions these elements may well determine the feasibility of conducting helicopter operations, especially at sea.

PRACTICAL TRAINING EXERCISE

Now that you have some background information about environmental briefings, it is time to apply what you have learned. This exercise involves you and either your supervisor, the duty officer, or your chief. Talk to one of them and arrange a time to complete the following:

1. Work up a DD Form 175-1 for a local round-robin flight.
2. Work up a DD Form 175-1 for a cross-country flight with at least one stop along the way.
3. Conduct a flight briefing for both 1 and 2 above for your supervisor, duty officer, or leading chief.
4. Prepare and conduct a route planning briefing for a task force departing Norfolk for the Mediterranean or departing San Diego for Subic Bay in the Philippines.
5. Conduct a local area weather briefing for your peers giving the synoptic situation, and current and forecast conditions for the next 36 hours.

This practical training exercise should be informal. Do not expect too much of yourself at first. Be as thorough as possible in your preparation and strive to follow the rules of good public speaking.

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UNIT 6

SPECIAL PHENOMENA, PRODUCTS, AND COMPUTATIONS

FOREWORD

As an Aerographer's Mate, you are required to know a great deal about the atmosphere and the weather phenomena within it. One of the primary duties of Aerographer's Mates is briefing others on atmospheric phenomena and their effects on operations.

Today, Aerographer's Mates use many products to help them determine environmental conditions. Most of the products are computer generated and are received via computer networks or are generated in-house, using computer software. Of course, there are still a few manually produced products, such as the Skew T, Log P Diagram.

Although computers do the majority of the computations necessary to produce environmental products, there may be times that you will be tasked with such duties. Computers are not infallible, and they do suffer "downtime." You could be required to compute ballistic winds, atmospheric refractivity, tides, etc., when computers or computer products are not available.

Unit 6 is broken down as follows:

Lesson 1—Weather Phenomena of Interest to Aviators

Lesson 2—Analyzing the Skew T, Log P Diagram

Lesson 3—Refractivity

Lesson 4—Electrooptics

Lesson 5—Sound Focusing

Lesson 6—Tides and Tidal Computations

Lesson 7—Computing Sunrise and Sunset

Lesson 8—Computing Moonrise and Moonset

Lesson 9—Radiological Fallout

UNIT 6—LESSON 1

WEATHER PHENOMENA OF INTEREST TO AVIATORS

OVERVIEW	OUTLINE
Identify the flight hazards associated with thunderstorms.	Thunderstorms
Identify the factors necessary for structural ice formation, the various forms of structural ice, the factors that influence the rate of ice accumulation on aircraft, and those regions of the atmosphere where icing is most apt to occur.	Icing
Identify the causes of turbulence, how it is classified, and where it is most likely to occur.	Turbulence
Identify the weather phenomena that can produce low-level wind shear.	Low-level wind shear
Recognize the processes within the atmosphere that bring about the formation and dissipation of fog and stratus, and identify the various types of fog.	Fogs and stratus
Define density altitude, pressure altitude, vapor pressure, and specific humidity, and recognize their importance in aircraft operations.	Air density and water vapor
Define *d-value* and recognize how d-values are computed.	D-values
Identify the three types of condensation trails, and recognize how they form.	Condensation trails

AVIATION PARAMETERS

Aviation weather office personnel are required to know a great deal about weather and its effects on aircraft. In this lesson, I will discuss various aviation weather phenomena, such as icing, turbulence, and low-level wind shear.

THUNDERSTORM WEATHER HAZARDS

Some of the basic information on thunderstorms was discussed previously in unit 5, lesson 4 of *AG 2* - Volume 1. Although reviewing that material is not absolutely necessary, you may find it helpful to review it before going on.

Obviously, you should tell pilots to avoid thunderstorms if possible. However, with 44,000 thunderstorms occurring daily over Earth's surface, almost every pilot will end up flying in or near one eventually.

Learning Objective: Identify the flight hazards associated with thunderstorms.

Thunderstorms and cumulonimbus clouds may be accompanied by extreme turbulence, icing, lightning, precipitation, and gusty surface winds. The more severe thunderstorms produce hail and sometimes tornadoes.

Turbulence

Hazardous turbulence is present in all thunderstorms, and in a severe thunderstorm it can damage an airframe and cause serious injury to passengers and crew. The strongest turbulence within the cloud occurs with shear between updrafts and downdrafts. Outside the cloud, shear turbulence has been encountered several thousand feet above and 20 miles laterally from a severe storm. Severe turbulence can be encountered in the anvil 15 to 30 miles downwind. Remember, storm clouds are only the *visible* portion of a turbulent system, whose updrafts and downdrafts often extend outside the storm proper.

A low-level turbulent area is the shear zone between the cold air downdraft and the surrounding air. This often occurs up to 10 or 15 miles ahead of a mature storm and is called the *gust front*. At times, second or third gust fronts are found between the first gust front and the thunderstorm base, because of multiple downdrafts in the storm. Horizontal wind direction averages a 40 percent change-of-direction across the gust front, and wind speed may increase as much as 50 percent between the surface and 1,500 feet. Thus, the surface observation may not give a true estimate of the actual wind above the surface.

Often a "roll cloud" on the leading edge of a storm marks the eddies to this shear. The roll cloud is most prevalent with cold-front or squall-line thunderstorms and indicates an extremely turbulent zone.

Hail

Hail is regarded as one of the worst hazards of thunderstorm flying. It usually occurs during the mature stage of cells having a strong updraft. As a rule, the larger the storm, the more likely it is to have hail. Hail has been encountered as high as 45,000 feet in completely clear air and may be carried up to 10 miles downwind from the storm core. Hail can occur anywhere in a thunderstorm, but it is usually found beneath the anvil of a large cumulonimbus.

Hailstones larger than 1/2 to 3/4 inch can cause significant aircraft damage in a few seconds.

Icing

Icing should be expected where ambient (free-air) temperatures are at or below freezing. In general, icing is associated with temperatures from 0 °C to −40 °C. The most severe icing occurs from 0 °C to −10 °C, while the heaviest icing conditions usually occur just above the freezing level. Since the freezing level is also the zone where heavy rainfall and turbulence most frequently occur, this particular altitude appears to be the most hazardous.

Lightning and Electrostatic Discharges

Lightning occurs at all levels in a thunderstorm. The majority of lightning discharges never strike the ground but occur between clouds or within the same cloud. However, aircraft flying several miles from a thunderstorm can still be struck by the proverbial "bolt out of the blue." Electrical activity generated by a thunderstorm may continue to exist even after the thunderstorm itself has decayed. This electrical activity may drift downstream and is usually found within the cirrus deck that at one time was connected to the thunderstorm cell.

A charge also may build up on an aircraft after it has been flying through clouds and precipitation, including snow as well as rain, or solid particles such as dust, haze, or ice. The larger the aircraft and the faster it flies, the more particles it impacts, generating a greater charge on the aircraft. The electrical field of the aircraft may interact with the cloud, and an *electrostatic discharge* may then occur. Electrostatic discharges usually cause only minor physical damage and indirect effects, such as electrical circuit upsets.

Lightning strikes and electrostatic discharges are two of the leading causes of reported

weather-related aircraft accidents and incidents. All types of aircraft are susceptible to lightning strikes and electrostatic discharges. Aircraft have been struck by lightning or have experienced electrostatic discharges on the ground or at altitudes ranging to at least 43,000 feet. Most lightning strikes occur when aircraft are operating in one or more of the following conditions:

- Within 8 °C of the freezing level
- Within about 5,000 feet of the freezing level
- In precipitation, including snow
- In clouds
- In some turbulence

It should be noted that all of these conditions do not have to occur for a lightning strike or an electrostatic discharge to take place.

Lightning strikes can cause severe structural damage to aircraft. Damage to aircraft electrical systems, instruments, avionics, and radar is also possible. Transient voltages and currents induced in the aircraft electrical systems, as well as direct lightning strikes, have caused bomb doors to open, activated wing-folding motors, and made the accuracy of electronic flight-control navigational systems questionable.

Pilots and crew are not immune to the effects of lightning strikes either. Flash blindness can last up to 30 seconds, and the shock wave can cause some temporary hearing loss if headphones or some form of hearing-loss-protection gear is not worn. Some aircrews have even experienced a mild electric shock and minor burns.

Tornadoes and Waterspouts

Tornadoes are violent, rotating columns of air that descend with a familiar funnel (or tube) shape from a cumulonimbus cloud. If the cloud does not reach the surface, it is called a *funnel cloud*; if it touches water, it is called a *water spout*. A tornado vortex is normally several hundred yards wide.

Within the tornado's funnel-shaped cloud, winds can attain speeds up to 300 miles per hour, while the forward speed of the tornado averages only 40 knots.

Tornadoes occur with isolated thunderstorms at times, but much more frequently they form with thunderstorms associated with fast-moving cold fronts or squall-lines.

Families of tornadoes or tornadic vortices have been observed as appendages of the main cloud, extending 20 miles outward from the area of lightning and precipitation. They may last from a few minutes up to 6 hours. These vortices usually occur on the southern or southwestern flank of the storm. Tornadic vortices can be masked by innocent-looking cumulus clouds trailing the thunderstorm and may or may not be visible to alert the unwary crew member. The invisible vortices may only be evidenced by swirls in the cloud-base or by dust-whirls boiling along the ground, but may be strong enough to cause severe structural damage to the aircraft.

Phenomena frequently encountered by naval personnel are waterspouts. Waterspouts fall into two classes: tornadoes over water and fair-weather waterspouts.

The fair-weather waterspout is comparable to a dust devil; it may rotate in either direction, whereas the other type of waterspout rotates cyclonically. In general, waterspouts are not as strong as tornadoes, in spite of the large moisture source and the reduced friction. The water surface under a waterspout is either raised or lowered, depending on whether it is effected more by the atmospheric pressure reduction or by the wind force. There is less inflow and upflow of air in a waterspout than in a tornado. The waterspout does not lift any significant amount of water from the surface. Ships passing through waterspouts have mostly encountered fresh water.

ICING

The formation of ice on lift-producing airfoils (wings, propellers, helo rotors, and control surfaces) disrupts the smooth flow of air over these surfaces. The result is decreased lift, increased drag, and increased stall speed of fixed-wing aircraft.

Most aircraft that are normally loaded can fly with icing conditions ongoing and, under normal circumstances, the danger is not too great. When aircraft are critically loaded, however, icing is extremely important. The formation of ice on some structural parts of an aircraft can cause vibration and place added stress on those parts. For example, vibration caused by a small amount of ice unevenly distributed on a delicately balanced rotor or propeller can create dangerous stress on the system, transmission, and engine mounts.

Learning Objective: Identify the factors necessary for structural ice formation, the various forms of structural ice, the factors that influence the rate of ice accumulation on aircraft, and those regions of the atmosphere where icing is likely to occur.

Factors Necessary for Structural Ice Formation

Factors necessary to produce structural icing on aircraft in flight are (1) the ambient temperature must be at or below freezing and (2) visible liquid moisture in the form of clouds or precipitation must be present.

AMBIENT AIR TEMPERATURE.—Ice can form when saturated air flows over stationary aircraft with ambient temperatures as high as 4 °C (39 °F). Aircraft on an airfield or flight deck are subject to such icing. When an aircraft is stationary and the ambient temperature lowers to near freezing (1 °C to 4 °C), the aircraft's structural surfaces may freeze because of evaporation and the pressure changes caused by the moving air.

When an aircraft is flying through saturated air, its structural surfaces are heated by friction and the impact of waterdrops. Because the heating and the cooling of moving objects tend to balance, structural ice does not form unless the outside air temperature is at or below freezing (0 °C). The most severe aircraft icing occurs in layers of air whose ambient temperature is between 0 °C and −10 °C.

CLOUDS AND PRECIPITATION.—Clouds are the most common form of visible liquid moisture. However, not all clouds with below-freezing temperatures produce serious icing conditions. Serious icing conditions are rare in temperatures below −20 °C. Pilots must be made aware, however, that structural icing is possible in even colder temperatures.

Rain and drizzle are forms of precipitation (liquid moisture) that can form ice when conditions are right. When rain and/or drizzle fall through layers of air whose ambient temperature is at or below freezing, the droplets become supercooled. When the supercooled droplets strike an object, such as an aircraft, they freeze. Freezing rain can build hazardous amounts of ice in a few minutes, and the ice is extremely difficult to break loose from aircraft structures.

Types of Aircraft Structural Ice

Aircraft structural icing may be clear, rime, a combination of clear and rime, or frost. The type of ice that forms on a moving object normally depends on (1) the ambient air temperature, (2) the surface temperature of the object, (3) the characteristics of the surface of the structure (configuration, roughness, etc.), and (4) the size of the waterdrops.

CLEAR ICE (GLAZE).—Clear ice, also know as glaze, is the most serious form of structural ice. The large supercooled water droplets that cause glaze strike an aircraft, and spread out on or around the movable and nonmovable surfaces of the aircraft before they freeze. Glaze adheres firmly to exposed surfaces, and since it is transparent or translucent, it may go undetected until it is too late for deicing methods to remove it.

When clear ice is transparent, it resembles ordinary ice. When it mixes with snow, sleet, or small hail, the glaze may be rough, irregular, and whitish.

Glaze forms on the leading edge of airfoils and antennas, where it takes on a blunt-nose shape. The glaze tapers toward the trailing edge.

RIME ICE.—Rime is a white or milky, opaque, granular deposit of ice created by small supercooled water droplets. It is normally encountered in stratiform clouds where the temperature ranges between 0 °C and −20 °C or in cumuliform clouds with temperatures between −10 °C and −20 °C.

Rime ice is not as compact as clear ice, and the small supercooled water droplets do <u>not</u> spread out before they freeze. Rime ice forms and accumulates on the leading edge of exposed parts, producing rough, irregular formations.

FROST.—Frost is formed through the process of sublimation; ice crystals form when water vapor contacts a cold surface. Frost may form in the air and on the ground. When aircraft descend through a cold layer of air into a layer of warm, moist air, frost formation is possible. It may also form at flight level when aircraft pass from a subfreezing air mass into a moist and slightly warmer air mass. On the ground, frost may form during a clear night with subfreezing temperatures.

Pilots tend to underestimate the flight hazards of frost formation; therefore, you must make sure they understand its dangers. On a windshield, frost can restrict visibility or cause total loss of visibility. And at low airspeeds, during takeoff and landing, frost is particularly hazardous because it increases drag.

Rate of Accumulation

Four factors influence the rate of ice accumulation on an aircraft: (1) the amount of liquid water, (2) droplet size, (3) airspeed, and (4) the aircraft's size and shape.

AMOUNT OF LIQUID WATER.—Ice formation is more rapid in cloud formations that are thick and continuous. Icing increases as the amount of supercooled liquid water in the air increases.

DROPLET SIZE.—As aircraft move, they push or deflect the air. The faster they fly, the stronger is the airflow across their surface. When aircraft pass through clouds or precipitation, the small water droplets tend to move with the deflected airstream, and not to collect on airfoils or structural parts. Larger droplets resist the deflecting influence. More large supercooled droplets will strike an aircraft, thereby increasing the rate of ice accumulation.

AIRSPEED.—The rate of ice formation is increased, to a point, by an increase in airspeed. But at very high speeds, such as those attained by jet aircraft, the situation is reversed. At high speeds, friction creates enough heat on the skin of jet aircraft to melt structural ice. Icing is seldom a problem at airspeeds in excess of 575 knots. However, the airspeed at which frictional heating prevents ice formation varies with aircraft (type, configuration, surface characteristics, etc.) and the ambient air temperature. Helicopter cruise speeds will control the rate of ice accumulation. Blade and rotor speeds of 570 to 575 knots are common at normal cruise speeds; therefore, frictional heat precludes ice buildup at the outboard portion of the main rotor blades. The chance of ice buildup increases inboard toward the rotor disk.

AIRCRAFT SIZE AND SHAPE.—The size, shape, and smoothness of aircraft surfaces and airfoils also control the rate of ice accumulation. Ice accumulates at a faster rate on large, non-streamlined aircraft with rough surface features than it does on thin, smooth, highly streamlined aircraft. However, even on the best surfaces, once ice forms, it presents a larger surface area on which freezing droplets can collect, and the rate of accumulation is accelerated.

Distribution of Icing in the Atmosphere

The atmospheric distribution of potential icing zones is mainly a function of temperature and cloud structure. These factors, in turn, vary with altitude, synoptic situation, orography (physical geography of mountain ranges), location, and season.

ICING AND TEMPERATURE.—Aircraft icing is generally limited to the layer of the atmosphere lying between the freezing level and the −40 °C isotherm. However, icing has occasionally been reported at temperatures colder than −40 °C in the upper parts of cumulonimbus and other clouds. In general, the frequency of icing decreases rapidly with decreasing temperature, becoming rare at temperatures below −30 °C. The normal vertical temperature profile is such that icing is usually restricted to the lower 30,000 feet of the troposphere. The types of icing generally associated with temperature, and their ranges, are (1) clear, 0 °C to −10 °C; (2) a mixture of clear and rime, −10 °C to −15 °C; and (3) rime, 15 °C to −20 °C, with possible rime occurring at lower temperatures.

ICING IN RELATION TO CLOUD TYPE.—Stable air masses often produce stratus-type clouds, with extensive areas of relatively continuous icing conditions. Unstable air masses generally produce cumulus clouds, with a limited horizontal extent of icing conditions, where the pilot can expect the icing to become more severe at higher altitudes in the clouds. The type and amount of icing will vary considerably with each type of cloud.

Stratiform Clouds.—Icing in middle- and low-level stratiform clouds is confined, on the average, to a layer between 3,000 and 4,000 feet thick. However, pilots frequently encounter situations where multiple layers of clouds are so close together that visual navigation between layers is not feasible. In such cases, the maximum depth of continuous icing conditions rarely exceeds 6,000 feet. The intensity of icing generally ranges

from light to moderate, with maximum values occurring in the upper portions of the cloud. Both rime and mixed icing are observed in stratiform clouds. The main hazard lies in the great horizontal extent of some of these cloud decks. High-level stratiform clouds are composed mostly of ice crystals and give little icing.

Cumuliform Clouds.—The zone of probable icing in cumuliform clouds is smaller horizontally but greater vertically than in stratiform clouds. Icing is more variable in cumuliform clouds because many factors conducive to icing depend greatly on the stage of development of the cloud. Icing intensities may range from generally light in small supercooled cumulus to moderate or severe in cumulus congestus and cumulonimbus. The most severe icing occurs in cumulus congestus clouds just before their change to cumulonimbus. Although icing occurs at all levels above the freezing level in a building cumulus, it is most intense in the upper half of the cloud. In a mature cumulonimbus, icing is generally restricted to the updraft regions; and in a dissipating thunderstorm, to a shallow layer near the freezing level. Icing in these types of clouds is usually clear or mixed.

Cirroform Clouds.—Aircraft icing rarely occurs in cirrus clouds, although some cirrus do contain a small proportion of water droplets. Icing of moderate intensity, however, has been reported in dense cirrus and the anvil-tops of cumulonimbus, where updrafts may maintain considerable water at rather low temperatures.

ICING IN FRONTAL ZONES.—About 85 percent of all icing conditions reported is associated with frontal zones. Therefore, Aerographer's Mates should have a thorough knowledge of the danger areas in the frontal zones so that pilots may be properly briefed. The basic approach to forecasting icing in frontal zones is to relate the front to the cloud types in them.

The stratified cloud system associated with the lifting of warm, moist air over a warm front often reaches dangerous subzero temperatures, where rime or glaze icing will occur. If the warm air mass is conditionally unstable, cumuliform clouds may form. These clouds are favorable to the formation of glaze or rime or a combination of both. Figure 6-1-1 shows a typical warm-front structure, with the most probable icing zones and a possible flightpath to minimize exposure to icing. The cloud system of a warm front is extensive, and since a flight through such a system is a long one, the icing dangers are therefore increased.

Cumuliform clouds are associated with cold fronts. Glaze and mixed icing can be expected in them. The cloud systems are usually relatively narrow as compared with those of a warm front; therefore, the time spent flying through them is shorter. But because of the heavy precipitation, icing can be rapid and extremely dangerous even though it is of short duration.

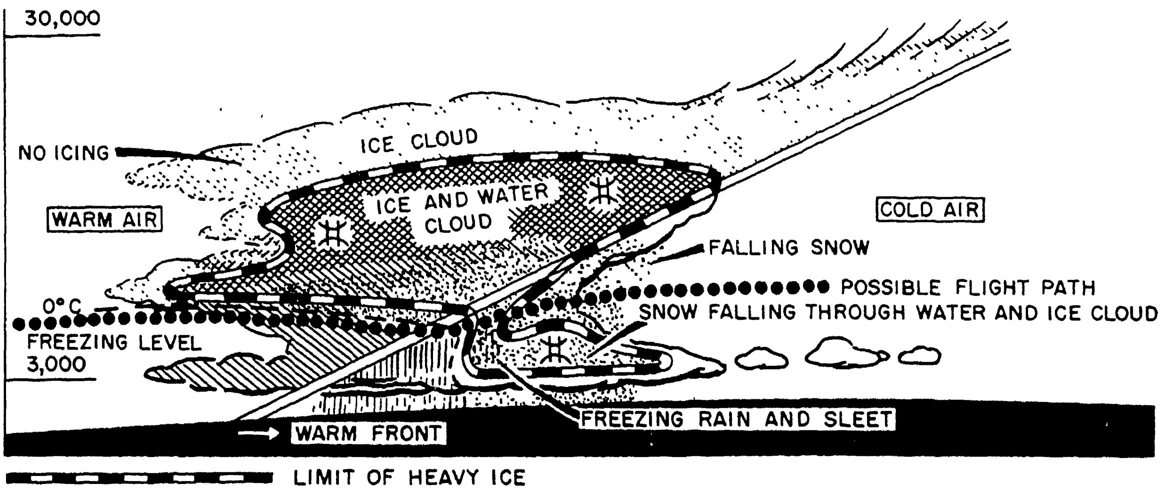

Figure 6-1-1.—Warm-front icing condition.

Figure 6-1-2 illustrates a typical cold-front icing situation.

Occluded fronts present less of an icing hazard, because precipitation has been occurring for some time and the cloud system contains less water. Since the cloud system is extensive, however, accumulation may be dangerous.

OROGRAPHIC INFLUENCES.—The lifting of conditionally unstable air over mountain ranges is one of the most serious ice-producing processes experienced in the United States. When mT air moves northward and eastward over the Appalachian Mountains, it is often cooled to subfreezing temperatures. An icing hazard exists for all air traffic that must travel through that air. Similarly, in winter, maritime polar (mP) air approaching the west coast of the United States contains considerable moisture in its lower levels. As it is forced aloft by the successive mountain ranges encountered in its eastward movement, severe icing zones develop.

The movement of a front across a mountain brings together two important factors that aid in the formation of icing zones. A study of icing in the Western United States has shown that almost all cases, the ice occurred where the air was blowing over a mountain slope or up a frontal surface or both.

The most severe icing zones over mountains will be above the crests and slightly to the windward side of the ridges. The icing zones usually extend about 4,000 feet above the tops of the mountains. In the case of unstable air, they may extend higher.

Learning Objective: Identify the cause of turbulence, how it is classified, and where it is most likely to occur.

TURBULENCE

Turbulence in the atmosphere is rapidly becoming the only weather element that cannot be partially overcome by mechanical devices. Therefore, turbulence is of major importance to all pilots and also to Aerographer's Mates whose duty is to recognize situations where turbulence may exist and to forecast for flight operations both the probable areas and the intensity of turbulence. In this chapter, we cover the causative factors, classifications, and locations of turbulence.

Turbulence Characteristics

Turbulence may be defined as irregular and instantaneous motions of the air that are made up of small eddies traveling in the current of air. Atmospheric turbulence is caused by random fluctuations in the flow of wind. Given a wind field with both streamlines and isotachs drawn

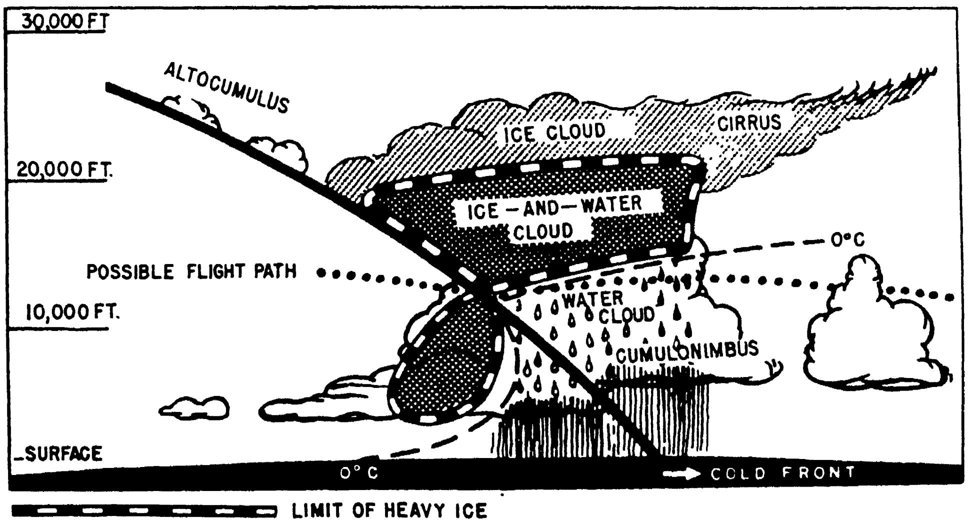

Figure 6-1-2.—Icing zones along a cold front.

smooth, any difference between the actual wind field and the smooth field is attributed to turbulence.

To an aircraft in flight, the atmosphere is considered turbulent when irregular whirls or eddies of air affect the motion of the aircraft, and a series of abrupt jolts or bumps is felt by the pilot. The type of motion felt by the occupants of an aircraft is directly related to the size and intensity of the eddies in the atmosphere. When the eddies have a diameter smaller than the aircraft, a rapid upward and downward fluctuation is felt, similar to what you might feel in a car running over a series of two-by-fours on a road. This is often referred to by pilots as *chop*. When the eddies have a diameter about the same size or slightly larger than the size of the aircraft, a sharp downward and then upward jolt is felt within the aircraft, similar to that caused by running a vehicle through a pothole just longer than the length of the vehicle. When atmospheric eddies are encountered that are much greater than the size of the aircraft, a sudden dropping or climbing sensation is felt. This may be related to cresting a sharp hill in a rapidly moving car. The differences in intensity of turbulence are caused by the changes in vertical velocity between the ambient air and the air within an eddy, and may be equated to changes in the depth of a pothole in the road. As different vehicles will respond differently to road irregularities based on their weight and size, different size and weight aircraft will respond differently to similar situations in the atmosphere. Keep in mind the following guidelines:

- The effect of turbulence is directly proportional to the speed of the aircraft. A faster aircraft will feel turbulence more than a slower aircraft.

- The effect is inversely proportional to the weight of the aircraft. A heavier aircraft will feel less turbulence than a lighter aircraft.

- The effect is directly proportional to the wing area of the aircraft. An aircraft with a larger wing area will feel the same turbulence more than an aircraft with a smaller wing area.

For pilots and aircrew, turbulence reporting is subjective at best. Judgment of turbulence severity is influenced by the factors listed above, by the time that the aircraft is in the turbulence, and by the attitude of the person reporting the turbulence (turbulence severity increases directly with the length of the crew day). The established turbulence-reporting criteria in table 6-1-1 are related to the effect of turbulence on the aircraft and its occupants. Many aircraft lack adaquate equipment to measure rapid airspeed fluctuations or vertical gust velocities, so turbulence reported by the pilot is still an estimate.

Types of Turbulence

The atmosphere is turbulent everywhere, but often the intensity of the turbulence is so small that it has little effect on aircraft operations. Large intensities of turbulence are to be expected whenever *horizontal wind shear* or *vertical wind shear* is great, or wherever instability exists. There are two overall classifications for turbulence, based on how the turbulence is initiated. These are thermal turbulence and mechanical turbulence. Both types may occur either in clouds or in clear air. When conducting an aircrew brief, the Aerographer's Mate uses the term *CAT* (clear air turbulence) to alert the aircrew where to expect turbulence.

THERMAL TURBULENCE.—*Thermal turbulence* is the effect (felt by aircraft) that is caused by wind shear (changes in wind speed and/or direction) directly produced by surface heating. As a surface is heated by solar radiation, the air above it is warmed through contact. The warm air becomes unstable and rises in uneven and irregular motions, causing eddies and gusts. If sufficient low-level moisture is present, convective cells may form giving rise to convective turbulence. All turbulence caused by heating is *classified* as thermal turbulence. The term *thermal turbulence* is also used to identify the *type* of generally light turbulence experienced in clear air in the lower (10,000 feet) atmosphere caused by heating of the surface.

Thermals.—As Earth's surface is heated by the Sun, different types of surfaces heat at different rates. Water heats slowly; forests heat slightly quicker; grasslands heat faster than forests; and desert sand heats the most rapidly. Each different surface warms the air above it through contact and re-radiation of long wave (thermal) energy. When the air near a homogenous surface becomes warmer than the air above it, the surface air begins to rise and mixing occurs. Cooler air from the upper layer sinks to replace the rising heated air. The rising parcels

Table 6-1-1.—Turbulence-reporting Criteria

TURBULENCE CLASS	OPERATIONAL CRITERIA		VERTICAL GUST VELOCITY, FT/SEC
	CONDITIONS IN THE PLANE	AIRSPEED FLUCTUATION, KNOTS	
LIGHT	A turbulent condition during which occupants may be required to use seat belts but objects in the aircraft remain at rest.	5 to 15	5 to 20
MODERATE	A turbulent condition during which occupants require seat belts and occasionally are thrown against the belt. Unsecured objects in the aircraft move about.	15 to 25	20 to 35
SEVERE	A turbulent condition during which the aircraft may be momentarily out of control. Occupants are thrown violently against the belt and back into the seat. Objects not secured in the aircraft are tossed about.	>25	35 to 50
EXTREME	A rarely encountered turbulent condition during which the aircraft is violently tossed about and is practically impossible to control. May cause structural damage.	rapid fluctuations in excess of 25	>50

of air are called *thermals*. If the thermal continues to develop and becomes large enough, it will produce turbulence. When different types of surface are located in the proximity of one another, thermals develop and intensify at different rates, which intensifies the scale and effect of the thermals. Typically, the slower warming areas will become the locus of a sinking column of air, and the faster warming areas will form the center of a sustained upward thermal. Thermals will normally develop a slight cyclonic spin. Strong prevailing winds will usually prevent thermals from developing. The formation of the stronger thermals usually coincides with maximum solar heating, during the late afternoon.

Turbulence is felt when an aircraft flies through thermals into areas of stable or sinking air. A light "chop" may be felt when flying through numerous thermals with diameters smaller than the size of the aircraft, but light or moderate turbulence may be felt if the diameter exceeds the size of the aircraft. The vertical velocity of the thermal is an important factor in the severity of the turbulence. Moderate or severe turbulence may be expected when penetrating strong thermals over arid desert areas. These will usually be visible and avoidable because of the large amount of dust and debris picked up in the stronger updrafts.

Some guidelines for briefing thermal turbulence to aircrews are as follows:

- Expect light thermal turbulence on days with light winds when the surface temperatures

are expected to produce an unstable lapse rate in the lower few thousand feet. Keep in mind that large blacktop and concrete areas will heat faster.

- Expect light turbulence in areas where dust devils are occurring or typically occur under similar conditions.

- Expect moderate thermal turbulence in areas where extreme heating and low humidity are expected or where exceptionally large dust devils normally occur under similar situations.

- Expect light thermal turbulence under areas of developing cumulus clouds.

Thermals rarely exceed 10,000 feet AGL without forming clouds and being classified as convective turbulence.

Convective Turbulence.—The appearance of cumulus clouds indicates a great deal of turbulence. In general, the taller the cloud, the more turbulence there is. The initiating mechanism in convective-type turbulence is thermal instability. The roughness is caused by the large wind shears between the updrafts and downdrafts.

The intermingling of the downdrafts and the updrafts results in moderate to severe turbulence, particularly at the boundary between regions of precipitation and regions having no precipitation. This result was confirmed by radar studies of thunderstorms that were made in this country and in England. Severe turbulence occurs in regions of strong echoes, and particularly in regions of sharp boundaries of echoes.

The intensity of turbulence in thunderstorms seems to increase with height, well past the middle of the clouds. The actual turbulent velocities may increase to even greater elevations but have less effect on aircraft, because the air density is lower at higher levels. The air within the cloud subsides in the last stage of the thunderstorm and the storm dissipates, leaving no indication of having severe turbulence.

The present methods of estimating the turbulence expected in cumuliform clouds before the clouds have formed generally make use of the temperature differences between the interior of the cloud and the surrounding air. Refer to Unit 6, Lesson 2 for a method used to calculate convective turbulence using the Skew T, Log P Diagram.

MECHANICAL TURBULENCE.—*Mechanical turbulence* is the effect of wind shear (changes in wind speed and/or direction) caused by physical features. These physical features may be geographic features, such as Earth's surface (ranging from flat ground to high mountains); or they may be physical features of the atmosphere, such as jet streams, frontal surfaces, or inversions. The wind shear that causes mechanical turbulence may be an abrupt change in the speed or direction of wind in either the horizontal or the vertical or both. In this section we will discuss the different mechanisms that produce mechanical turbulence, and their effect on aircraft.

JET STREAM TURBULENCE.—Jet stream turbulence is produced by both strong horizontal and vertical wind-speed shears in the vicinity of the jet streams. Since the jet streams are usually located well above all but the cirrus clouds, and the location of jet stream turbulence is not directly associated with cirrus cloudiness, jet stream turbulence is often briefed as CAT.

Jet stream turbulence effects many commercial and military aircraft. The usual location of the jet streams is from 30,000 to 40,000 feet, which is also the optimum flying altitude for most jet aircraft. Of all reports of turbulence received, only 20 percent of these reports were related to the jet streams. However, over two thirds of all reports of *severe* turbulence were associated with the jet stream.

Turbulence occurs all around the axis of the jet stream core because of the large increase in wind speed encountered while progressing into the region of the core. The least turbulence is usually encountered at the level of the jet core on the equatorial side. Figure 6-1-3 shows cross-sectional areas around the jet stream where patches of turbulence are usually reported. It is a distribution diagram showing areas where turbulence is most often located and the strength of the turbulence most often reported in those areas. Do not imply that the areas shown are one solid area of turbulence.

Where the jet stream is in a relatively straight line, the turbulence tends to be concentrated both above and below the jet core on the polar side (fig. 6-1-3, part A). Little or no turbulence occurs within the jet stream core. In areas where the jet stream follows a trough and is curved cyclonically, the strongest turbulence tends to be located below the jet core toward the colder air advection, as in part B. In part C, we see that when the jet stream is curved anti-cyclonically, the area of

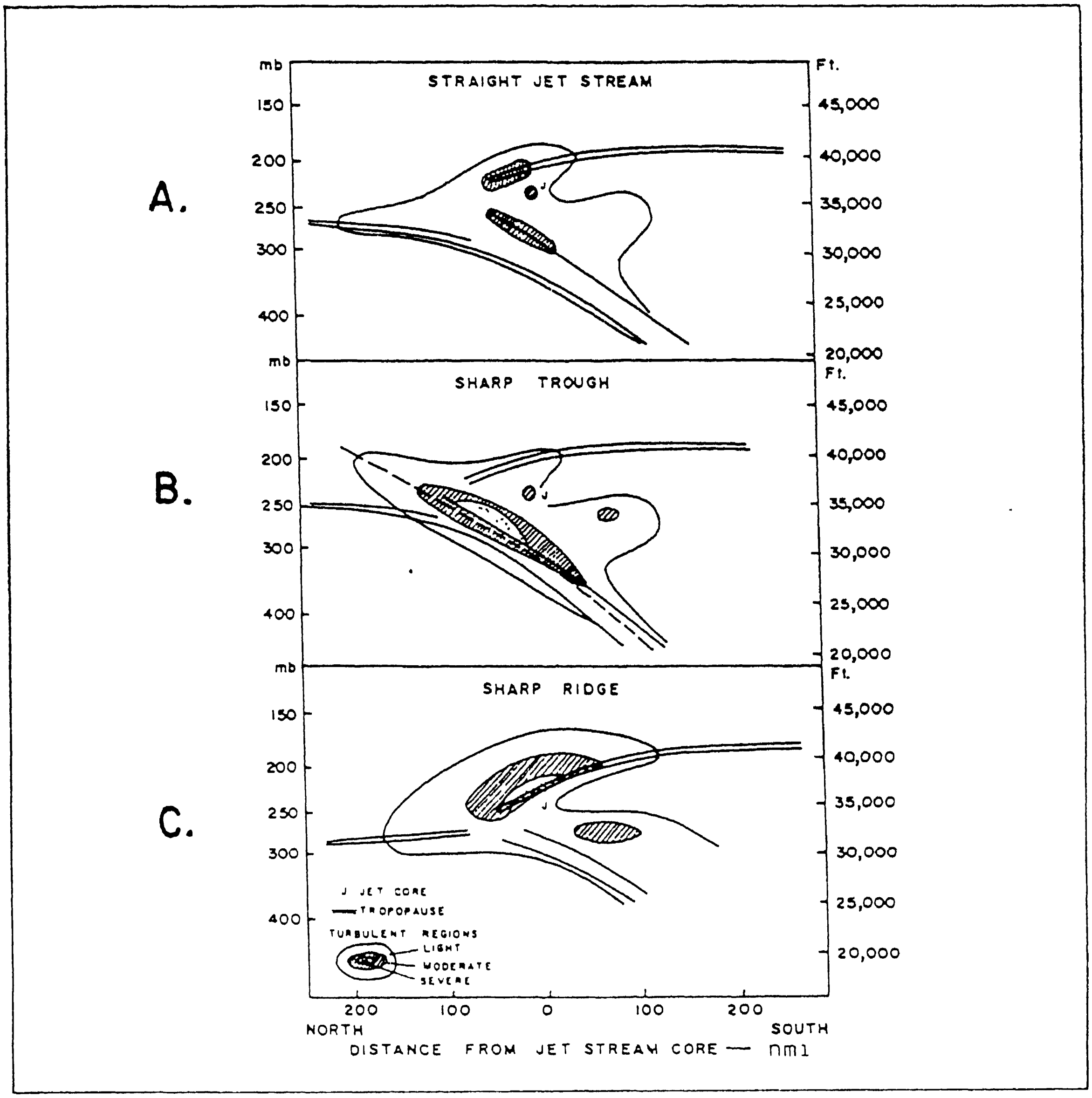

Figure 6-1-3.—Ideal locations for CAT occurrence near jet streams.

turbulence tends to be most concentrated at the tropopause above the jet core on the polar side. Data also indicated that CAT is less frequently encountered over ocean areas than over continents, although the CAT patches over the oceans seem to be larger than those overland. The average thickness of a turbulent layer is about 2,000 feet. In the horizontal, the turbulent patches often are from 10 to 40 nmi wide (across the direction of the wind flow) and usually extend about 50 nmi above land and 100 nmi over water in the direction of the wind flow.

When jet streams appear to merge on a constant pressure chart, such as the 300-millibar analysis, the colder jet stream core actually lies under the warmer jet core. The area of the intersection and westward of the intersection are typically favorable areas for strong CAT occurrence because of the directional shear of the underlying northwesterly jet and the overlying southwesterly jet.

Calculation of the horizontal and vertical speed shears will yield the strength of the turbulence that may be expected. The critical

values of the speed differences and the associated turbulence intensities are listed in table 6-1-2. In cases where evaluation of directional shear must be made, turbulence within the shear zone can be calculated by taking the *vector difference* of the vertical winds in the column being evaluated. Compare this difference to the turbulence criteria in the vertical wind shear column of table 6-1-2. Review *AG2*, Volume 1, Unit 2, Lesson 1 if you need to refresh yourself on vector addition and subtraction.

Calculations For Horizontal Wind Shear.— The calculations for horizontal shear may be done relatively quickly on plotted constant pressure charts using a set of dividers. Set your dividers for a one-and-a-half-degree-of-latitude spread at the latitude you are investigating. From the plotted wind reports or the isotach lines (20-knot interval), estimate the change in wind speed across the spread of the dividers and relate the change to the turbulence intensity in table 6-1-2. A second method of delineating an area of turbulence uses the spacing between the analyzed isotachs (20-knot interval). A spacing between isotachs of more than 1.2 degrees of latitude means that the wind speed change is less than 25 knots per 90 nautical miles, or that the turbulence is light. A spacing between 1.2 degrees of latitude and 0.9 degree of latitude means the wind speed

Table 6-1-2.—Wind Shear Turbulence Criteria

HORIZONTAL AND VERTICAL WIND SPEED SHEAR		
Horizontal Wind Speed Shear, kn/90 nmi	Vertical Wind Speed Shear, kn/1,000 ft	CAT Intensity
<25	3 to 5	LIGHT
25 to 49	6 to 9	MODERATE
50 to 89	10 to 15	SEVERE
>90	>15	EXTREME

DIRECTIONAL WIND SHEAR						
Mean Wind Speed in Layer, knots	Vector Wind Shear Difference in the Vertical, kn/1,000 ft					
	5-7	8-10	11-20	21-30	31-50	>50
40 to 60	N	L	L-M	M	M-S	S
61 to 120	L	L-M	M	M-S	S	S-X
>120	L	L-M	M	M-S	S	X

N = None L = Light M = Moderate S = Severe X = Extreme

the warm air mass and the cooler air mass, and comparing this difference to the turbulence criteria in the vertical wind shear column of table 6-1-2.

When the transition zone is extremely narrow, as in a fast-moving cold front, the turbulence through the transition zone will be very brief for any aircraft transiting the front. However, the abrupt change in wind direction will be more of a hazard to the aircraft than the turbulence. This wind shear hazard will be discussed in more detail in the next section.

The remainder of the turbulence experienced in the vicinity of frontal zones will be associated with convective activity or be the result of high winds producing low-level turbulence.

LOW-LEVEL TURBULENCE.—The lowest 50 millibars of the atmosphere is topped by the boundary layer. Within this layer, the geostrophic winds are affected by friction as they interact with Earth's surface. Progressing downward from the boundary layer to the surface, wind speeds decrease logarithmically and back directionally. Overland, we generally expect a 50-percent decrease in speed and a 30-degree backing in direction; while over water, we can expect a 70-percent reduction in speed and a 15-degree backing in direction from the boundary layer to the surface. The frictional increase when nearing the surface causes a mixing of air, as numerous vertical eddies are formed. These eddies produce wind shear, which is felt as turbulence by aircraft. The strength of the turbulence may be calculated based on the type of terrain and the strength of the wind speed. See table 6-1-3 for the low-level turbulence threshold values.

MOUNTAIN WAVE TURBULENCE.—The most severe type of terrain-induced wind shear turbulence is mountain wave turbulence. This turbulence occurs when the wind flow across a mountain is disturbed, creating eddy currents. Turbulence from mountain waves has been experienced at altitudes up to 40,000 feet. Even low mountains may create turbulence that can extend to a height 25 times that of the mountain. The intensity of the wave is a function of height, degree of slope of the mountain, and the strength of the wind.

Formation Criteria for Mountain Waves.—Several conditions must be present for a mountain wave to form. They are as follows:

- The component of the wind perpendicular to the mountain ridge at the mountain top level must be 25 knots or greater.

Table 6-1-3.—Low-level-Wind-Induced Turbulence Thresholds[1]

Terrain	Surface Wind and/or Gusts, knots	Turbulence Intensity and Max Height
Relatively flat or smooth terrain	30 to 39	Light to 3,000 feet
	40 to 49	Light to Moderate to 3,000 feet
	>50	Moderate to 5,000 feet
Rough terrain (mountainous regions) Also check other mountain wave turbulence areas	20 to 24	Light to 3,000 feet above ridge height
	25 to 34	Light to Moderate to 5,000 feet above ridge height
	35 to 49	Moderate to 5,000 feet above ridge height
	>50	Severe to 5,000 feet above ridge height

[1]Thresholds are for the 727, C-9, C-130, F-4, F-5, F-14, F-15, F-16, and F-106 aircraft, which have similar turbulence sensitivities. Very light and rotary wing aircraft may experience more turbulence; while extremely heavy aircraft, such as the B-52 and C-5, may experience less.

● The wind direction must be within 50° from the perpendicular to the mountain range (ridge line). The closer the direction to perpendicular, the stronger the wave.

● On the leeward (downwind) side of the mountain, the atmosphere should be adiabatically stable or there must be an inversion present that extends at least up to the height of the mountain peaks. This stability or an inversion prevents convective instability from breaking up the wave pattern. This also implies that low-level convective clouds should never be observed when a mountain wave exists.

● There should be a rapid increase in wind speed with altitude from the level of the mountain peak to several thousand feet above the mountain peak. Above this, there should be a steady strong flow up to the tropopause, with speeds increasing gradually. A very rapid increase all the way to the tropopause can eliminate the wave. A jet stream will frequently be located over the mountain range when mountain wave turbulence is observed.

Distribution of Clouds and Turbulence.—Specific clouds are associated with the mountain wave condition. They are the cap (foehnwall), rotor or roll, lenticular, and nacreous (mother-of-pearl) clouds. Figure 6-1-5 illustrates the

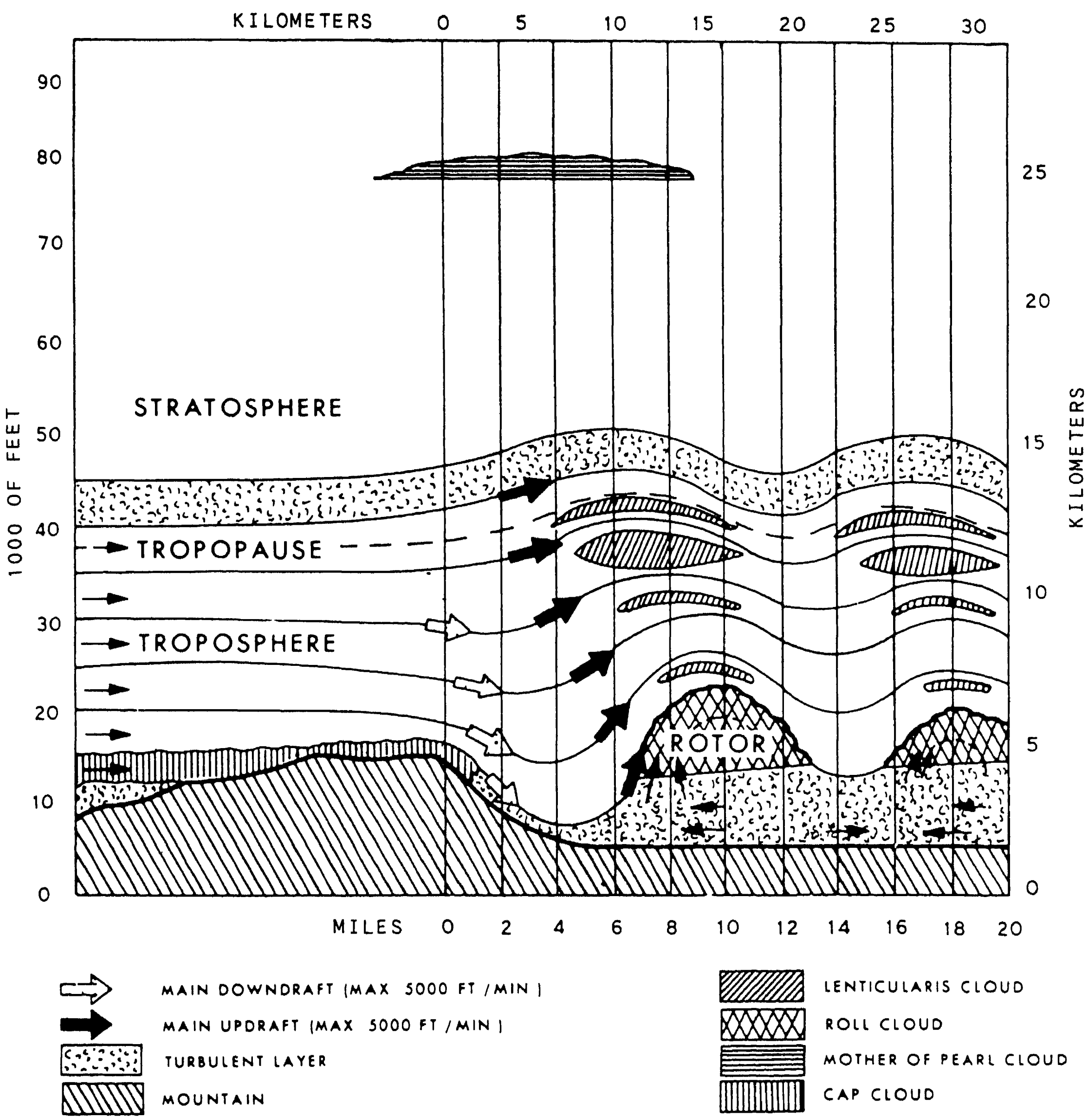

Figure 6-1-5.—Mountain wave structure.

structure of a strong mountain wave and the associated cloud patterns. The lines and arrows illustrate the wind flow from left to right.

The cap cloud hugs the tops of the mountains and flows down the leeward side with the appearance of a waterfall. This cloud is dangerous because it hides the mountain and has strong downdrafts. The downdrafts may be as strong as 5,000 feet per minute.

The roll or rotor cloud looks like a line of cumulus clouds parallel to the ridge line. It forms on the lee side and has its base near the height of the mountain peak, with its top extending considerably above the peak. The tops may extend to twice the height of the highest peak. The rotor often merges with the lenticulars above, forming a solid mass to the tropopause. Rotor clouds are noted for their ragged leeward edge, where it appears the cloud is being torn apart. The rotor cloud is dangerously turbulent. It has updrafts up to 5,000 feet per minute (83 feet per second) on the windward edge, and downdrafts up to 5,000 feet per minute on the leeward edge. This cloud is stationary, constantly forming on the leading edge and dissipating on the trailing (downwind) edge. The primary or first roll cloud may form immediately on the lee side of the mountain, or it may form up to 10 miles downstream from the mountain ridge. Several successively weaker bands of roll clouds may form at intervals downstream from the primary roll cloud and merge into a stratocumulus cloud formation. The stratocumulus clouds also form bands paralleling the mountain peaks. The ragged rotor appearance is less evident in each succeeding band, and the turbulence is less extreme with each band. These bands are very evident on satellite imagery and are often seen extending 150 to 300 miles downwind of a mountain range.

The lenticulars are lens-shaped clouds with bases above the primary roll cloud. The tops may extend to 40,000 feet. They may have a tiered or stacked shape due to the stratified moisture of the atmosphere. The lenticulars may or may not have turbulence associated with them. If they have smooth edges, there is no turbulence; if the edges are ragged, the aircrew should expect turbulence.

In the polar regions a high stratospheric lenticular cloud often appears to be associated with a mountain wave. These clouds are called nacreous, or mother-of-pearl, clouds and form in the vicinity of 80,000 feet.

The clouds in the mountain wave form in pyramids on the lee side of mountains. They are usually tilted backward toward the mountain. One pyramid may form; a series of pyramids extending downstream may form; or no clouds at all may form. The appearance of clouds in a mountain wave depicts the existence of turbulence with sufficient moisture to form clouds. The lack of clouds means only that there is insufficient moisture for cloud formation; turbulence may still be present.

The winds blowing across the mountains (which produce the mountain wave) also produce a notable pressure deviation, which can in itself be hazardous during IFR conditions. Anticipate station pressures and altimeter settings within 50 nmi of the windward side of the mountain to be as much as two-tenths of an inch (7 millibars) higher than anticipated, and pressures within 50 nmi of the leeward side to be as much as two-tenths of an inch lower than anticipated. One source cites a 1-inch (35 millibars) altimeter deviation in the immediate lee side of steep mountains under high wind conditions. The buildup of mass will produce a windward side high-pressure ridge and a leeward side low-pressure trough. Pressure fluctuations will continue downwind but with rapidly decreasing intensity. An aircraft flying a low-level route during IFR conditions approaching the mountain from the windward side would see an indicated altitude on the pressure altimeter lower than he is actually flying, and would correct by adding altitude. This would increase his margin of safety crossing the mountain peaks. However, the same aircraft flying from the leeward side to the windward side would encounter the lee side trough, see an indicated altitude higher than that actually being flown, and compensate by decreasing his altitude. A two-tenths-of-an-inch altimeter deviation would roughly equate to about two hundred feet. While fighting the downdraft in the soup of the cap cloud, a shirt-tail flyer may count on that extra 200 feet of altitude (which he never had) to "just squeeze over" the top of the mountain.

The most dangerous feature of the mountain wave is the turbulence located in the cap and the rotor cloud. The downdrafts in these clouds can force an aircraft into the mountain. Pilots investigating mountain waves have reported that they experienced more hazardous flight conditions

in the wave than they encountered in any thunderstorm. Mountain waves have produced gust velocity measurements of 50 feet per second at 30,000 feet. Some aircraft will experience structural failure when encountering gusts of 50 feet per second at reduced speeds or 35 feet per second at ordinary speeds.

Table 6-1-4 is a summary of areas of turbulence during mountain wave conditions.

Table 6-1-4.—Mountain Wave Turbulence Guide

Wind at Ridge Level	Turbulence	Location of Turbulence
25 to 50 knots	Severe	• Patches within 2,000 to 3,000 feet of tropopause up to 150 nmi downstream of ridge. • Immediate lee of ridge. • In rotor clouds.
	Moderate	• Patches surface to 5,000 feet above ridge level, up to 150 nmi downstream. • In ragged lenticulars • At bases of other stable layers below tropopause.
	Light	• Patches surface to well above tropopause and to 200 nmi downstream.
>50 knots	Extreme	• Immediate leeward side of ridge line. • In rotor clouds.
	Severe	• In patches surface to 5,000 feet above ridge from ridge line to 150 nmi downstream. • Within 5,000 feet of tropopause from ridge to 150 nmi downstream. • In ragged altocumulus lenticular clouds.
	Moderate	• In patches surface to 10,000 feet above ridge level from the ridge line to 300 nmi downstream. • Within 10,000 feet of tropopause.
	Light	• In patches from surface to well above the tropopause from ridge line to over 300 nmi downstream.

Learning Objective: Identify the weather phenomena that can produce low-level wind shear.

LOW-LEVEL WIND SHEAR

Wind shear is a change in wind speed and/or direction over a short distance, which results in a tearing or shearing action. Although wind shear can occur at any altitude, it is particularly hazardous when it happens over a short period of time and within 2,000 feet of the ground, during takeoff or landing. During this phase of flight, the aircraft operates only slightly above stall speed, and a major change in wind velocity can lead to a loss of lift. If the loss is great enough that power response is inadequate, it results in a steep descent. The altitude at which the encounter occurs, pilot reaction time, and airplane response capability determine if the descent can be altered in time to prevent an accident.

The time dependency of significant low-level wind shear can best be illustrated through example: Suppose that an aircraft flying into a headwind of 30 knots were to fly through a gradually changing wind pattern such that 1 hour later the headwind had become a tailwind of 30 knots. The effect of such a gradual shear would be negligible. But if the same change were to occur within a few seconds, the aircrew would have to make rapid, positive inputs to maintain control of the aircraft.

Weather Causing Low-Level Wind Shear

Several weather phenomena produce low-level wind shear. Included are thunderstorms, fronts, low-level jets at the top of a radiation inversion, and funneling winds and mountain waves.

THUNDERSTORMS.—The winds around a thunderstorm are complex. Downdrafts or microbursts exiting the base of a thunderstorm spread outward in all directions upon approaching the surface and form an area of gustiness near the thunderstorm. The outer limit of this gusty area is referred to as the *gust front*. Figure 6-1-6 shows a cross section of a typical gust front.

The thunderstorm downdraft may produce the most dangerous shear conditions associated with the outflow of a thunderstorm. The gust front frequently extends 10 to 15 miles away from the thunderstorm. Extreme wind shears of 10 knots per 100 feet of altitude have been measured immediately behind the gust front, while horizontal wind shears of 40 knots per mile have been recorded across the gust front. In addition to the tremendous speed shears reached, the most severe thunderstorms produce directional shears of 90° to 180°. See figure 6-1-7.

Wind shear associated with thunderstorms is by far the most hazardous, because of the complexity and multiplicity of the shears

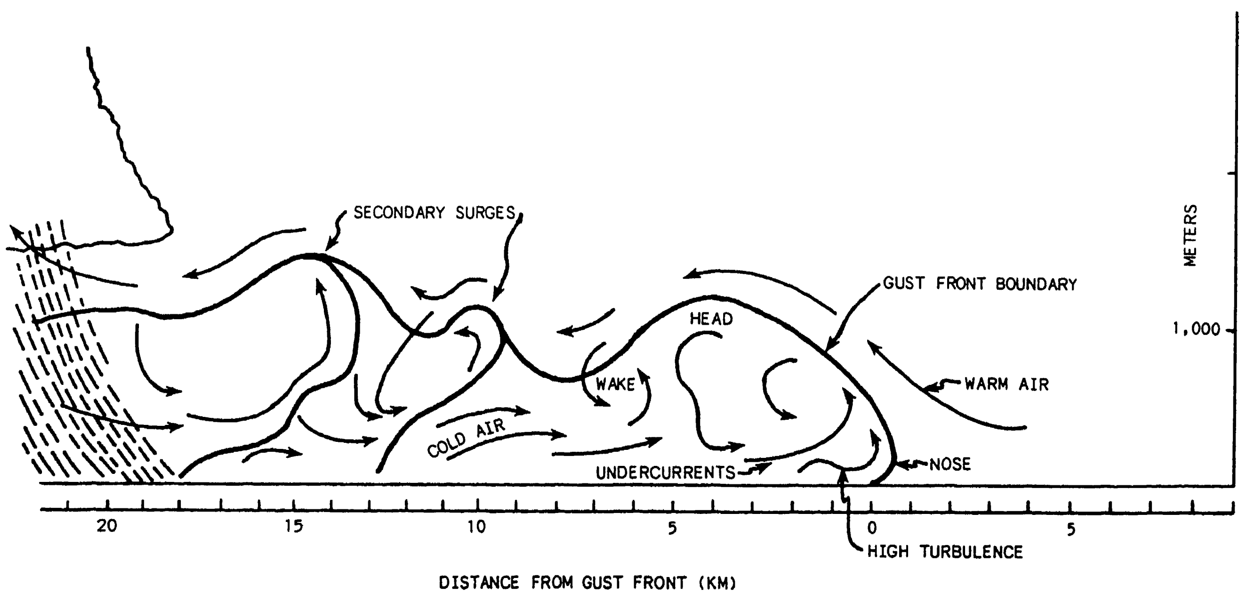

Figure 6-1-6.—Common features of a gust front.

warm fronts, low-level wind shear usually lasts less than 2 hours.

The wind shear associated with a warm front is more dangerous to airport operations. Strong winds aloft, associated with the warm front, may cause a rapid change in wind direction and speed where the warm air overrides the cold, dense air near the surface. Warm-frontal wind shear may persist 6 hours or more ahead of the front because of the front's shallow slope and slow movement. Further, low ceilings and visibilities frequently associated with warm fronts may compound aircrew problems.

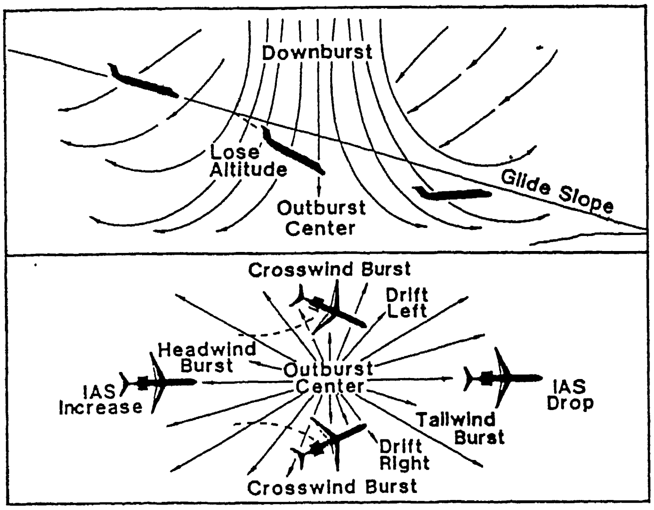

Figure 6-1-7.—Microburst effects on aircraft.

produced. Prevailing low-level winds are forced up over the gust front; currents that feed into the storm are present; and more than one gust front may be encountered, because of multiple downdrafts. In addition, extreme downdrafts may occur beneath the central region of the storm.

FRONTS.—Winds can be significantly different in two air masses forming a front. Fronts that are most conducive to significant wind shear are fast moving (30 knots or more) and/or have at least a 5°C (10°F) temperature differential. Figure 6-1-8 may be used as a general guideline to determine if a front will have wind shear and/or turbulence associated with it.

Low-level wind shear occurs with a cold front after the front passes. Because cold fronts have a greater slope and normally move faster than

LOW-LEVEL JET AT THE TOP OF A RADIATION INVERSION.—A low-level jet often forms just above a radiation inversion. It starts to form at sundown, reaches maximum intensity just before sunrise, and is destroyed by daytime heating (usually by 10 a.m. local time). The low-level jet is observed in all parts of the world at all times of the year. In the United States it is common in the Great Plains and the Central states. Radiational cooling creates a calm, stable dome of cold air 300 to 1,000 feet thick, termed an inversion layer. The low-level jet occurs just above the top of the inversion layer, and while speeds of 30 knots are common, windspeeds in excess of 65 knots have been reported. Anytime a radiation inversion is present, the possibility of low-level wind shear exists.

FUNNELING WINDS AND MOUNTAIN WAVES.—Certain airports are infamous for having treacherous winds. These winds are caused by funneling; that is, the terrain is such that the prevailing winds force a large mass of air to be channeled through a narrow space (such as a canyon), where it is accelerated, and then it spills out into the flightpath of aircraft. These winds

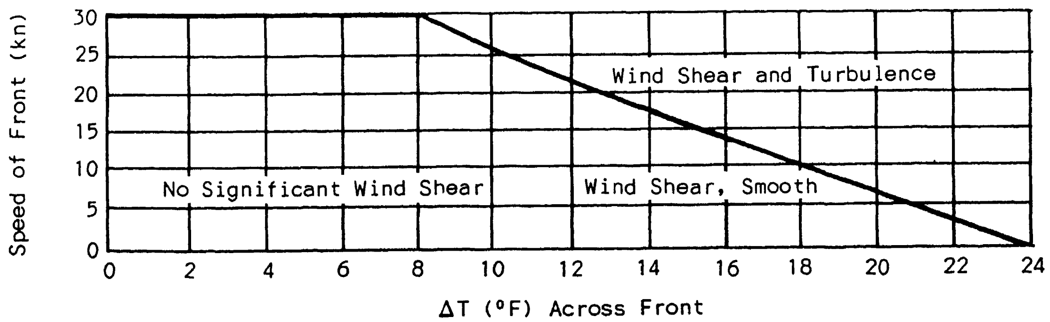

Figure 6-1-8.—Frontal wind shear/turbulence guide.

sometimes reach velocities of 80 knots. Caution is required when operations are conducted near mountains or along straits and channels.

Mountain waves often create low-level wind shear at airports downwind of the wave. While altocumulus standing lenticular (ACSL) clouds are not a prerequisite, they usually indicate the presence of mountain waves, and they are clues that shear should be anticipated.

Other Causes of Low-Level Wind Shear

Two less-prominent sources of low-level wind shear deserve brief discussion: gusty or strong surface winds, and land/sea breezes. Fluctuations of 10 knots or more from the mean sustained wind speed, or strong winds blowing past buildings and structures near a runway can produce localized areas of shear. This type of shear can be particularly hazardous to light aircraft. Observing the local terrain and requesting pilot reports of conditions near the runway are the best means for anticipating wind shear from this source.

Land and sea breezes commonly occur near large lakes, bays, or oceans. The flow to or from the water is caused by the differential heating and cooling of land and sea surfaces. The sea breeze is a small-scale frontal boundary and can reach speeds of 15 to 20 knots. It can move inland 10 to 20 miles, reaching its maximum penetration in mid- or late afternoon. The depth of the breeze is approximately 2,000 feet. Land breezes occur at night, because the land becomes cooler than the water. The land breeze has less intensity than the sea breeze, and unless aircraft penetrate it during a long, low over-water approach, there is little threat to flying safety.

Learning Objective: Recognize the processes within the atmosphere that bring about the formation and dissipation of stratus and fogs, and identify the various types of fog.

STRATUS AND FOGS

Stratus clouds and fogs occur at or near the surface of Earth and can seriously restrict visibility at low levels. Therefore, they are a very important consideration in aircraft operations, particularly in connection with landings and takeoffs. Fogs are especially significant to the pilot who limits his flying to visual flight rules, because ceilings under stratus clouds often are very low, and visibilities in fog conditions often are not sufficient to permit navigation by visual reference. Too, fogs are of great concern to ships. In harbors and over open ocean areas, fogs constitute a definite hazard to safe navigation. For these reasons it is important that you have a basic understanding of the factors leading to the formation and dissipation of stratus and fogs, and the basic types of fog.

Stratus and fogs result from the condensation of excess water vapor out of a saturated air mass. Both are composed of small water droplets or small ice particles suspended in air. The main difference between them is that *fog* is a layer of suspended droplets adjacent to Earth's surface, while *stratus* is fog that has been lifted or has formed some distance above the ground. Moisture will not condense out of pure (nuclei-free) air until a high degree of supersaturation (from 400 to 800 percent humidity) is reached. The air within the troposphere is not nuclei-free. Moisture can condense on nuclei when relative humidity reaches approximately 100 percent. (Some nuclei become effective at relative humidities as low as 70 percent, which may produce haze and the beginning stages of fog.) The atmospheric nuclei believed important in the condensation process are sea-salt particles and certain hygroscopic products of combustion. The combustion nuclei are more common over industrial areas, but some condensation nuclei appear to be universally present.

Formation and Dissipation of Stratus and Fog

When an air mass cannot hold all of the water vapor contained in it, the excess vapor condenses out in the form of small droplets. Air can be brought to saturation by (1) cooling, (2) the addition of water vapor, or (3) the mixing of one air mass with another. Sometimes more than one process is involved, either simultaneously or one after another.

1. The cooling of an air mass may be caused by one or more of the following processes:

- Cooling of Earth's surface by outgoing nocturnal radiation, with resultant cooling of the lower layer of air

- Advection of air over a colder surface

- Adiabatic cooling of air by orographic, frontal, or turbulent lifting

- Cooling of air by the evaporation of precipitation falling through it

- Radiation from the air or the cloud to the environment (usually a slow and unimportant factor in fog)

2. The addition of moisture to an air mass may be brought about by one or more of the following processes:

- Evaporation from falling precipitation (under certain conditions)

- Evaporation from a wet surface, either land or sea

- Moisture resulting from the combustion of hydrocarbon fuels, such as gasoline and oil.

- Turbulent transfer of moisture upward (when a suitable vertical gradient of vapor pressure exists)

3. Increasing the temperature of the air can be caused by one or more of the following processes:

- Contact warming of the ground layer by incoming solar radiation during the day

- Advection over a warmer surface.

- Adiabatic warming of the air by subsidence, downslope motion, or the turbulent transfer of heat downward.

- Turbulent mixing of the fog layer with adjacent warmer air (above).

Fog and clouds can dissipate by either of two processes—the heating of air or the removal of moisture. A decrease in moisture content can be brought about in the lower layers by turbulent transfer of moisture upward, by turbulent mixing of the fog layer with adjacent drier air, or by the condensing-out of water vapor in the form of dew or frost.

Effect of Air-Mass Stability

Fog and stratus are typical phenomena of a warm-type (stable) air mass, since they require saturation of the layer at or near the surface of Earth. A warm-type air mass is one with a temperature greater than that of the underlying surface.

Instability causes vertical mixing, which tends to create an adiabatic lapse rate and a uniform moisture distribution throughout the turbulent layer. If initially the moisture decreases with height and the temperature lapse rate is less than dry adiabatic (the usual state of the atmosphere), mixing results in a net transfer of moisture upward and heat downward, decreasing the relative humidity at the surface and increasing it aloft. If the instability extends to only a short distance above the ground, a stratus or stratocumulus deck may form. If the instability extends to great heights, any clouds will be of the convective type.

Cooling from below exerts a stabilizing influence. Bear in mind, however, that there may be diurnal changes in the characteristics of an air mass, because of the heating of the land in the daytime and the cooling at night. Overland, the stability of an air mass is increased during the night, reaching a maximum near daybreak; during the day, the stability decreases, reaching a minimum in the late afternoon. Over the sea, the diurnal effect is small and usually negligible. An overcast condition reduces the heating and cooling effect and, consequently, the diurnal variation on stability.

Radiation cooling of the surface occurs mainly during clear, calm nights, such as those occurring in high-pressure areas. Meteorological soundings show the stability of an air mass, the presence of inversions, and the degree of saturation of the air. A warm air mass is stable in the lower layers, frequently showing a surface- or low-level inversion; the cold, unstable air mass has a near-adiabatic lapse rate. Fog is usually associated with a surface inversion; strato-type low clouds, with a low-level inversion above the surface.

Air-mass Fogs

Air-mass fogs consist of radiation, advection, advection-radiation, and upslope fogs. These fogs occur within an air mass. Air-mass fogs are not primarily the result of frontal activity. Radiation causes or contributes heavily toward the formation of nearly all fogs over the continents.

RADIATION FOGS.—Radiation fogs consist of ground fogs and high-inversion fogs. Both types of radiation fogs occur only overland. Ground fogs are the result of radiational cooling of the surface of the ground in a single night. High-inversion fogs, on the other hand, are due to the net loss of heat from the surface of the ground by radiation over a period of weeks or months. High-inversion fogs may last several days. Ground fog usually dissipates during the daytime a few hours after its formation.

Ground fogs are quite prevalent on calm, clear nights after a day during which there has been cloud cover. The cloud cover helps keep the temperature down during the day, so the temperature is already relatively low when radiation starts. These fogs are quite general over Earth's land surfaces, appearing frequently in mountain valleys and on the coastal plains of the United States.

High-inversion fogs take place only over the continents outside the tropics in winter. The winter fogs of the low valleys in the far western United States are good examples of high-inversion fogs. They occur most frequently in areas where mP air has become trapped in a valley and the moisture condenses when sufficient radiation has taken place. If an anticyclone with its accompanying subsidence causes the air mass to stagnate, the fog may last for several days. High-inversion fog owes its name to the strong inversion that is always found above the fog.

ADVECTION FOGS.—Advection fogs are caused by the transport of warm air over a cold surface or the transport of cold air over a warm surface. Included in advection fogs are land- and sea-breeze fogs, sea fogs, tropical-air fogs, and steam fogs.

Land- and sea-breeze fogs, which form along the eastern coast of continents, occur in summer. They also occur over large inland bodies of water, being quite frequent over the Great Lakes. Most of the fogs of the Great Lakes region are of this type. Radiation processes play a large role in the formation of these fogs.

Sea fogs occur any place where sea air is cooled over a cold ocean current. Therefore, sea fogs are not confined to coastal areas. Two outstanding examples of sea-fog formation are the prevalence of fogs in the vicinity of the Grand Banks of Newfoundland, and the Kamchatka Peninsula, in Asia. These fogs may persist even during times of strong winds and great turbulence, especially when the difference between the air temperature and the water temperature is large. Sea fogs are also quite persistent along the California coast, where sea air passes over the cold California Current.

Tropical-air fogs result from the gradual cooling of air as it flows over the oceans from low latitudes to high latitudes. They can also occur overland in winter as tropical air passes over cold land surfaces. This is probably the most common type of fog over open ocean areas. Some of the most widespread fogs in the United States are also of this type. Tropical-air fogs develop best over western Europe and the eastern North Atlantic. Sea fogs and tropical-air fogs are sustained up to much higher wind speeds than is the case for other fogs. Wind speeds of 30 knots in the midst of a sea fog or tropical-air fog are not uncommon.

Steam fogs occur when cold air with a low vapor pressure passes over warm water. If the water is quite warm, the air does not have to be very cold for the fog to form. The big factor is the difference between the vapor pressure of the air and the water. Wind speeds and temperature lapse rates do not have an appreciable effect on the formation of steam fogs. The Great Lakes region has steam fogs quite frequently in mid-winter, when cold continental air passes over the Great Lakes at a time when the temperature of the lake water is just above freezing.

ADVECTION RADIATION FOGS.—Advection radiation fogs occur when air that has come inland from the sea during the day undergoes nighttime radiational cooling. The special circumstances under which they form are what set them apart from other kinds of radiational fogs. The moisture-laden air comes in from the ocean, where its temperature was kept relatively low; it does not, therefore, take much radiational cooling for the air to reach its dew-point temperature and form fog. Advection radiation fogs take place mainly in late summer and autumn, when the water is warm enough to cause the air to have a high dewpoint and the nights are long enough to afford sufficient radiational cooling. This type of fog occurs primarily along the Gulf Coast, the Atlantic coastal plain and piedmont, in the vicinity of the Great Lakes, and in the coastal valleys of California.

UPSLOPE FOGS.—Upslope fogs form in regions where the land slopes gradually upward, as a result of the cooling of the air by adiabatic expansion as the air moves to higher elevations.

One such region is the Great Plains of the United States and Canada. This type of fog can occur in relatively high wind speeds. The faster the air moves up the slope, the more rapid will be the cooling. And to some extent, there will be a counteraction of the downward transport of heat by turbulence. Often these fogs are formed as the combined result of the ascent of the air and radiation and, occasionally, by increases of moisture due to rain.

Ice (Crystal) Fogs

When the air temperature is below about −04 °C, any water vapor in the air condensing into droplets is quickly converted into ice crystals. A suspension of ice crystals in the air at the surface of Earth is called ice fog. Ice fogs occur mostly in the Arctic regions and are mainly artificial fogs produced by human activities, occurring locally over settlements and airfields where hydrocarbon fuels are burned. (Burning 1 pound of hydrocarbon fuel produces 1.4 pounds of water.)

When the air temperature is approximately −01 °C or lower, ice fogs form very rapidly in the exhaust gases of aircraft, automobiles, or other types of combustion engines. When there is little or no wind, an aircraft can generate enough ice fog during landing or takeoff to cover the runway and a portion of the airfield. Depending on atmospheric conditions, ice fogs may last from a few minutes to several days.

A fine mist of ice crystals persists as haze over wide expanses of the Arctic basin during winter. The haze may extend upward through much of the troposphere—a sort of cirrus cloud reaching down to the ground.

Frontal Fogs

Frontal fogs are of three types: prefrontal (warm front), postfrontal (cold front), and frontal passage.

PREFRONTAL FOGS.—Prefrontal (warm-front) fogs occur in stable continental polar (cP) air when precipitating warm air overrides it, the rain raising the dew point sufficiently for fog formation. Generally, the wind speeds are slight, and the area most conducive to the formation of this type of fog is one between a nearby secondary low and a low-pressure center. In the entire world, the northeastern part of the United States is probably the most prevalent region of this type of fog. Prefrontal fogs are also of importance along the Gulf Coast, the Atlantic coastal plain, in the Midwest, and in the valleys of the Appalachians.

POSTFRONTAL FOGS.—As is the case with prefrontal fogs, postfrontal (cold-front) fogs are caused by falling precipitation. Fogs of this nature are widespread only when a cold front of an east-west orientation has become quasi-stationary and cP air is stable. This type of fog occurs frequently in the Midwest. Fog or stratiform clouds are prevalent for a considerable distance behind cold fronts associated with stable cP air masses in that region if the cold fronts have produced general precipitation.

FRONTAL PASSAGE FOGS.—During the passage of a front, fog may form temporarily if the winds accompanying the front are very light and the two air masses are near saturation. Also, temporary fog may form if the air is suddenly cooled over moist ground with the passage of a precipitating cold front. In low latitudes, fog may form in summer if the surface is cooled sufficiently by evaporation of rainwater that fell during frontal passage provided that the moisture addition to the air and the cooling are great enough to cause fog formation.

Learning Objective: Define *density altitude, pressure altitude, vapor pressure,* and *specific humidity* and recognize their importance in air operations.

AIR DENSITY AND WATER VAPOR

Air density and the water vapor content of the air have an important effect upon engine performance and the takeoff characteristics of aircraft. In this section, we will discuss some of the effects these two factors have upon engine takeoff, and the methods for computing these elements from a meteorological standpoint. The four most common elements an Aerographer's Mate is asked to furnish information on are pressure altitude, density altitude, vapor pressure, and specific humidity. All of these may be determined using a Density Altitude Computer. Pressure altitude and density altitude are given in feet; vapor pressure, commonly in inches and tenths of an inch of mercury; and specific

humidity, in grams per gram or in pounds per pound.

Air Density

The density of the atmosphere is a factor in many important problems in meteorology, as well as in the related sciences and engineering. The performance of an aircraft or missile depends on the density of the air in which it is flying. Pilots know that it is more difficult to take off from a high-altitude airport than from a low-altitude airport and that it is more difficult to take off on a hot afternoon than on a cool morning.

Since both temperature and pressure decrease with altitude, it might appear that the density of the atmosphere would remain constant with increased altitude. This is not true, for pressure drops more rapidly with increased altitude than does temperature. Since standard pressures and temperatures have been associated with each altitude, the density the air would have at those standard temperatures and pressures must be considered standard. Thus, there is associated with each altitude a particular atmospheric density. A density altitude of 15,000 feet is the altitude at which the density is the same as that considered standard for 15,000 feet. Remember, however, that density altitude is not necessarily true altitude. For example, on a day when the atmospheric pressure is higher than standard and the temperature is lower than standard, the density that is standard at 10,000 feet might occur at 12,000 feet. In that case, at an actual altitude of 12,000 feet, we would have air that has the same density as standard air at 10,000 feet.

PRESSURE ALTITUDE.—*Pressure altitude* is defined as the altitude of a given atmospheric pressure in the standard atmosphere. The pressure altitude of a given pressure is, therefore, usually a fictitious altitude, since it is equal to true altitude only rarely, when atmospheric conditions between sea level and the altimeter in the aircraft correspond to those of the standard atmosphere. Aircraft altimeters are constructed for the pressure-height relationship that exists in the standard atmosphere. Therefore, when the altimeter is set to standard mean sea level pressure (29.92 inches of mercury), it indicates *pressure altitude* and not true altitude. Flight levels, rather than true altitudes, now being flown above 18,000 feet in the United States and on overwater flights 100 miles offshore are based on an altimeter setting of 29.92 inches.

COMPUTATIONS FOR PRESSURE ALTITUDE.—The quickest method for approximating the pressure altitude is by using the Pressure Reduction Computer (CP-402/UM). Detailed instructions are listed on the computer. For your own station, you simply dial in the current station pressure and read the pressure altitude on the scale. The solution is more complex when converting forecast altimeter settings to pressure altitude, but the pressure reduction computer may still be used. On occasion, you may find yourself in a situation where this device is not available. Two alternate methods follow that will enable you to calculate approximations of the pressure altitude. Pressure altitude varies directly with the change in pressure multiplied by a complex variable. The variable amount takes into account *temperature* and *station elevation*. Both methods simplify the equation but still give fairly close pressure altitude approximations.

The first method uses a set of precalculated pressure altitudes based on pressure differences from standard pressure. These are listed in table 6-1-5.

Using the table, you may find the pressure altitude value corresponding to your current or forecast altimeter setting or the current or forecast altimeter setting for any other station. This value must be added to your station elevation or the other station's elevation to find the pressure altitude. For example, if your altimeter setting is 29.41 inches and your station elevation is 1,500 feet, you would enter the left side of the table with "29.4" and find the intersection of the column under "0.01" to find 476 feet. Add 476 feet to your station elevation, 1,500 feet, to find the pressure altitude of 1,976 feet.

You may also use the table to find pressure altitude using station pressure. Station elevation should NOT be added to the value when using station pressure.

The second method is useful when you do not have ready access to even the table. To calculate pressure altitude, use the formula

$$PA = H_A + PAV,$$

where PA = pressure altitude,

H_A = station elevation, and

PAV = pressure altitude variation approximation (or 29.92 minus current altimeter setting times 1,000).

Table 6-1-5.—Pressure Altitude Values

PRESSURE ALTITUDE TABLE										
Inches	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
	Feet									
28.0	1824	1814	1805	1795	1785	1776	1766	1756	1746	1737
28.1	1727	1717	1707	1698	1688	1678	1668	1659	1649	1639
28.2	1630	1620	1610	1601	1591	1581	1572	1562	1552	1542
28.3	1533	1523	1513	1504	1494	1484	1475	1465	1456	1446
28.4	1436	1427	1417	1407	1398	1388	1378	1369	1359	1350
28.5	1340	1330	1321	1311	1302	1292	1282	1273	1263	1254
28.6	1244	1234	1225	1215	1206	1196	1186	1177	1167	1138
28.7	1148	1139	1129	1120	1110	1100	1091	1081	1072	1062
28.8	1053	1043	1034	1024	1015	1005	995	986	976	967
28.9	957	948	938	929	919	910	900	891	881	872
29.0	863	853	844	834	825	815	806	796	787	777
29.1	768	758	749	739	730	721	711	702	692	683
29.2	673	664	655	645	636	626	617	607	598	589
29.3	579	570	560	551	542	532	523	514	504	495
29.4	485	476	467	457	448	439	429	420	410	401
29.5	392	382	373	364	354	345	336	326	318	308
29.6	298	289	280	270	261	252	242	233	224	215
29.7	205	196	187	177	168	159	149	140	131	122
29.8	112	103	94	85	75	66	57	47	38	29
29.9	20	10	+1	−8	−17	−26	−36	−45	−54	−63
30.0	−73	−82	−91	−100	−110	−119	−128	−137	−146	−156
30.1	−165	−174	−183	−192	−202	−211	−220	−229	−238	−248
30.2	−257	−266	−275	−284	−293	−303	−312	−321	−330	−339
30.3	−348	−358	−367	−376	−385	−394	−403	−412	−421	−431
30.4	−440	−449	−458	−467	−476	−485	−494	−504	−513	−522
30.5	−531	−540	−549	−558	−567	−576	−585	−594	−604	−613
30.6	−622	−631	−640	−649	−658	−667	−676	−685	−694	−703
30.7	−712	−721	−730	−740	−749	−758	−767	−776	−785	−794
30.8	−803	−812	−821	−830	−839	−848	−857	−866	−875	−884
30.9	−893	−902	−911	−920	−929	−938	−947	−956	−965	−974
31.0	−983	−992	−1001	−1010	−1019	−1028	−1037	−1046	−1055	−1064

Station pressure: read pressure altitude directly from table.
Altimeter setting: read value from table and add station elevation to find pressure altitude.

For example, using the formula for the same case we just calculated with the table, we find the following:

$$PA = H_A + PAV$$

$$PA = 1{,}500 + 1{,}000(29.92 - 29.41)$$

$$PA = 1{,}500 + 510$$

$$PA = 2{,}010 \text{ feet}$$

By comparison, you can see that this value is 34 feet higher than we found by using the table, but it is a close enough approximation when nothing else is available, and it may be done quickly in your head. With the pressure reduction computer, the same case yields a pressure altitude of 1,979 feet.

Pilots of aircraft, especially rotary wing aircraft, frequently ask for *maximum pressure altitude* both for take off and for all destinations. This is calculated using the lowest expected

altimeter setting (QNH) for the destination. The forecaster may have to interpret the other station's forecast to determine if the forecast QNH will be valid during the time the aircraft will be in the vicinity. Many rotary wing aircraft have a table in their aircraft technical data which is entered using maximum pressure altitude and maximum temperature to find the maximum permissible load that can be carried. Maximum pressure altitude may be used by the pilot in lieu of density altitude.

DENSITY ALTITUDE.—*Density altitude* is defined as the altitude at which a given density is found in the standard atmosphere. If, for example, the pressure at Cheyenne, Wyoming, (elevation 6,140 feet) is equal to he standard atmosphere pressure for 6,140 feet, but the temperature at that station is 101 °F, the density there is the same as that found at 10,000 feet in the standard atmosphere. The air is less dense than normal; therefore, an aircraft on takeoff (at approximately constant weight and power setting) will take longer to get airborne. Air density also effects airspeed. True airspeed and indicated airspeed are equal only when density altitude is zero. True airspeed exceeds indicated airspeed when density altitude increases.

No instrument is available to measure density altitude directly. It must be computed from the pressure (for takeoff, station pressure) and the virtual temperature at the particular altitude under consideration. This may be accomplished by using the Density Altitude Computer (CP-718/UM) or from Table 69, Density Altitude Diagram, of *Smithsonian Meteorological Tables*, NA-50-1B-521. Remember, virtual temperature is used in the computation of density altitude.

DENSITY ALTITUDE CALCULATIONS.—The quickest method of calculating density altitude is to use the Density Altitude Computer (CP-718/UM). Specific instructions are printed on the device. Density altitude results from the computer may be estimated to the nearest 10 feet between the marked increments of 100 feet. If you are in a situation where you do not have a density altitude computer or the *Smithsonian Meteorological Tables* available, you may calculate density altitude by the formula

$$DA = PA + (120\ V_t),$$

where DA = density altitude,

PA = pressure altitude at the level you desire density altitude,

120 = a temperature constant (120 feet per 1 °C), and

V_t = actual temperature minus standard temperature at the level of the pressure altitude.

For example, let's say the surface temperature is 30 °C and your pressure altitude is 2,010 feet. Look at table 6-1-6 and find the standard temperature corresponding to 2,000 feet. You should find 11 °C. Plug these values into the formula to find the following:

$$DA = PA + (120\ V_t)$$

$$DA = 2{,}010 \text{ feet} + [120(30\,°\mathrm{C} - 11\,°\mathrm{C})]$$

$$DA = 2{,}010 + 120(19)$$

$$DA = 2{,}010 + 2{,}280$$

$$DA = 4{,}290 \text{ feet}$$

For an acceptable result with slightly less precision, you may use the density altitude diagram (fig. 6-1-9) to obtain density altitude to the nearest 200 feet. Enter the bottom of the diagram with your air temperature and proceed vertically to the intersection of the pressure altitude line, then horizontally to the left side of the diagram to find the density altitude. The light dashed line shows an example using 22 °C and a pressure altitude of 10 feet, resulting in a density altitude of about 1,000 feet.

You may interpolate for more precise values, but this precision isn't often necessary for most density altitude calculations. (A quick method of determining standard temperatures in degrees Celsius for all levels up to 35,000 feet is to double the altitude in thousands of feet, subtract 15, and change the sign.)

Table 6-1-6.—U.S. Standard Atmosphere Heights and Temperatures

HEIGHTS TO STANDARD PRESSURE AND TEMPERATURE									
Altitude, feet	Pressure, mb	Pressure, inches	Temperature, °C	Temperature, °F	Altitude, feet	Pressure, mb	Pressure, inches	Temperature, °C	Temperature, °F
0	1013.2	29.92	15.0	59.0	26,000	359.9	10.63	−36.5	−33.7
1,000	977.2	28.86	13.0	55.4	27,000	344.3	10.17	−38.5	−37.3
2,000	942.1	27.82	11.0	51.9	28,000	329.3	9.72	−40.5	−40.9
3,000	908.1	26.82	9.0	48.3	29,000	314.8	9.30	−42.5	−44.4
4,000	875.1	25.84	7.1	44.7	30,000	300.9	8.89	−44.4	−48.0
5,000	843.1	24.90	5.1	41.2	31,000	287.4	8.49	−46.4	−51.6
6,000	812.0	23.98	3.1	37.6	32,000	274.5	8.11	−48.4	−55.1
7,000	781.8	23.09	1.1	34.0	33,000	262.0	7.74	−50.4	−58.7
8,000	752.6	22.22	−0.8	30.5	34,000	250.0	7.38	−52.4	−62.2
9,000	724.3	21.39	−2.8	26.9	35,000	238.4	7.04	−54.3	−65.8
10,000	696.8	20.58	−4.8	23.3	36,000	227.3	6.71	−56.3	−69.4
11,000	670.2	19.79	−6.8	19.8	37,000	216.6	6.40	−56.5	−69.7
12,000	644.4	19.03	−8.8	16.2	38,000	206.5	6.10	Constant to	
13,000	619.4	18.29	−10.8	12.6	39,000	196.8	5.81	65,500 feet	
14,000	595.2	17.58	−12.7	9.1	40,000	187.5	5.54		
15,000	571.8	16.89	−14.7	5.5	41,000	178.7	5.28		
16,000	549.2	16.22	−16.7	1.9	42,000	170.4	5.04		
17,000	427.2	15.57	−18.7	−1.6	43,000	162.4	4.79		
18,000	506.0	14.94	−29.7	−5.2	44,000	154.7	4.57		
19,000	485.5	14.34	−22.6	−8.8	45,000	147.5	4.35		
20,000	465.6	13.75	−24.6	−12.3	46,000	140.6	4.15		
21,000	446.4	13.18	−26.6	−15.9	47,000	134.0	3.96		
22,000	427.9	12.64	−28.6	−19.5	48,000	127.7	3.77		
23,000	410.0	12.11	−30.6	−23.9	49,000	121.7	3.59		
24,000	392.7	11.60	−32.5	−26.6	50,000	116.0	3.42		
25,000	376.0	11.10	−34.5	−30.2					

STANDARD PRESSURE SURFACES				
Pressure Surfaces (mb)	Height, feet	Height, meters	Temperature, °C	Temperature, °F
1000	364	111	14.2	57.8
850	4,781	1,457	5.5	41.9
700	9,882	3,012	−4.7	23.5
500	18,289	5,574	−21.3	−6.3
400	23,574	7,185	−31.7	−25.1
300	30,065	9,164	−44.7	−48.5
200	38,662	11,784	−56.7	−70.1
150	44,647	13,608	−56.7	−70.1
100	53,083	16,180	−56.7	−70.1

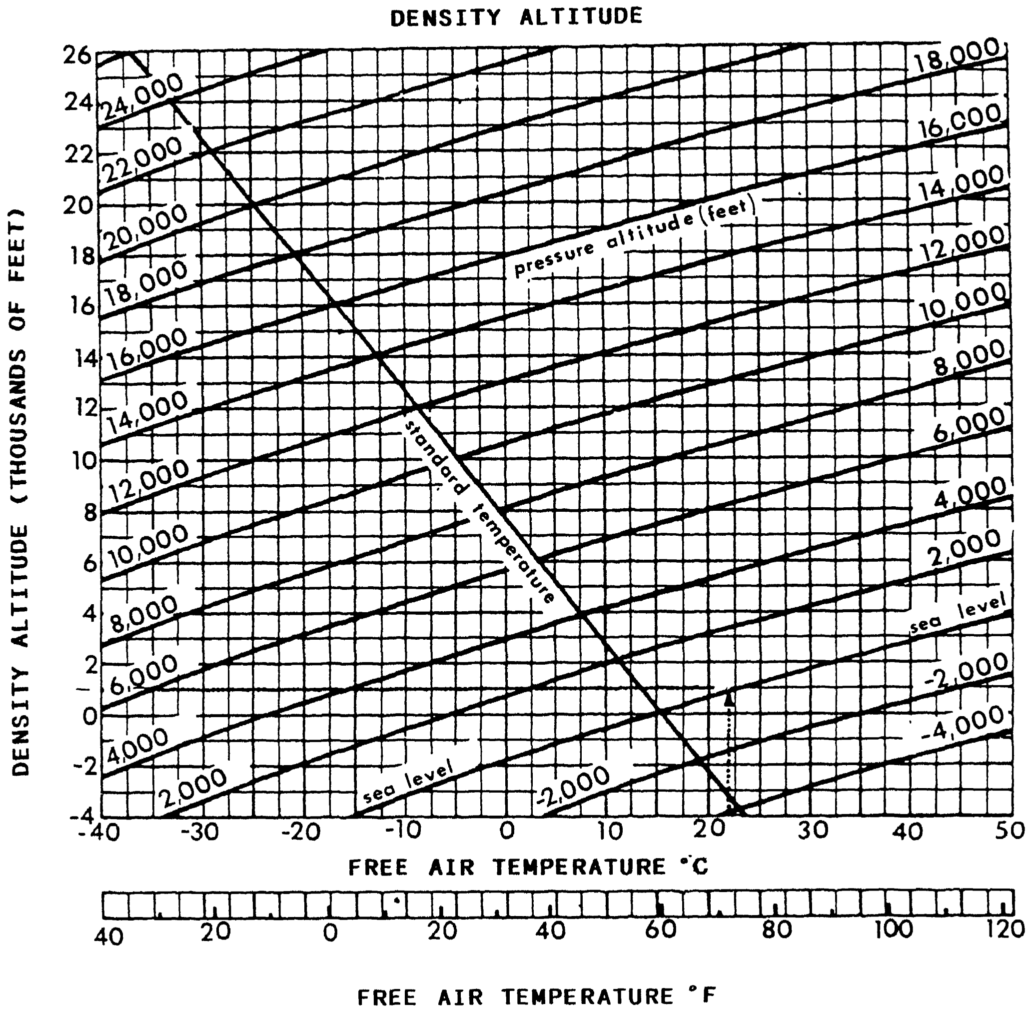

Figure 6-1-9.—Density altitude diagram.

Water Content of the Air

Fog and humidity affect the performance of aircraft. During takeoff, two things are done to compensate for their effect on takeoff performance. First, since humid air is less dense than dry air, the allowable takeoff gross weight is generally reduced for operations in areas that are consistently humid. Second, because power output is decreased by humidity, pilots must compensate for the power loss. Your main responsibility as an Aerographers's Mate is to ensure that the pilot has accurate information.

VAPOR PRESSURE.—*Vapor pressure* is that portion of the atmospheric pressure that is exerted by water vapor in the atmosphere. It is expressed in inches and tenths of an inch of mercury (Hg). The dew point for a given condition depends on the amount of water vapor present, so a direct relationship exists between vapor pressure and the dew point.

SPECIFIC HUMIDITY.—The mass of water vapor present in a unit mass of air is known as specific humidity. The mass of the unit of air is considered to be a unit mass of moist air. Since the mass of a unit of dry air differs but little from the mass of a unit of moist air, the mixing ratio and specific humidity are nearly numerically equivalent.

Where temperatures are high and rainfall is excessive, the water vapor content of the air reaches high proportions. Accurate information is required to determine the proper amount of horsepower needed for the takeoff roll. Specific

humidity and vapor pressure can be determined from the Density Altitude Computer.

Learning Objective: Define *d-value* and recognize how d-values are computed.

D-VALUES

D-values are used by pilots in planning pressure pattern flights. However, because of the size of pressure systems and the high speed of aircraft, as compared to wind speeds, pressure pattern flying is impractical for distances less than 1,000 miles. Today, most weather offices provide computer-generated flight plans that include d-values. You should, however, be familiar with d-values and know how they are computed.

A *d-value* is simply the *departure from the standard* height of a pressure surface. It is calculated by the formula

$$D = Z_A - Z_S,$$

Where D = d-value, in feet;

Z_A = actual height of a pressure surface, in feet; and

Z_S = standard height of a pressure surface, in feet.

For example, a radiosonde indicates the *actual* height of the 700-millibar level to be 2,990 meters (9,809 feet), while the *standard* height of the 700-millibar surface is 3,010 meters (9,875 feet). First, the height in meters was converted into feet by using table 6-1-7. Plugging these values into the formula, we find that D equals −66 feet, as follows:

$$D = Z_A - Z_S$$

$$D = 9{,}809 \text{ feet} - 9{,}875 \text{ feet}$$

$$D = -66 \text{ feet}$$

The minus sign means the actual height is lower than standard, while the difference of 66 feet tells us how much lower it is than standard.

The values may also be calculated from an upper air sounding as reported in meters, then the difference converted into feet.

To a pilot, the parameter *d* represents the difference between an aircraft's pressure altimeter reading and the actual altitude of the aircraft as shown on the aircraft's radar altimeter.

NOTE: Pressure altimeters are calibrated to read "0" when the air pressure is 29.92 inches of mercury. Radar altimeters are calibrated to read height-above-the-ground.

Since 29.92 Hg represents the standard atmospheric pressure at sea level, a pressure altimeter indicates the height of an aircraft in reference to sea level. Prior to takeoff, pilots set the pressure altimeter by inputting the airfield's current altimeter reading (the indicated altitude is the height of the airfield, as well as that of the aircraft, above sea level). Radar altimeters are calibrated to read "0" when aircraft are on the ground. Therefore, if an airfield is 65 feet above sea level, the pressure altimeter should read 65 feet, and the radar altimeter, zero.

How does all this relate to d-values? Since all aircraft are required to update their altimeter settings when flying below 18,000 feet MSL, d-values are of little use in this range overland. However, aircraft flying above 18,000 feet MSL or over ocean areas use Standard Sea Level Pressure (29.92 inches) for their altimeter setting. In most cases, these aircaft will fly their assigned flight level based on the pressure altimeter, regardless of what the radar altimeter shows, since use of the pressure altimeter is the standard. Not all aircraft have a radar altimeter. The d-value will give them the appropriate information to calculate their actual flight altitude if desired. More importantly, it is used by jet aircraft flight engineers who need the information to calculate fuel-burn rates. Fuel-burn tables are calculated for the various flight levels assuming a standard atmosphere. The d-value supplies an adjustment factor to compute more accurate fuel-use predictions. You will most often be asked to provide d-values for large jet aircraft flying at the higher altitudes.

For meteorological flight-planning, d-values are normally computed for standard levels within the atmosphere. For other levels, the pressure-altitude curve on the Skew T, Log P Diagram can be used to determine the height. The U.S. Standard Atmosphere heights are listed in table 6-1-6.

Table 6-1-7.—Meters-to-Feet Conversion

Meters	0	1	2	3	4	5	6	7	8	9
0	0.0	3.3	6.6	9.8	13.1	16.4	19.7	23.0	26.2	29.5
10	32.8	36.1	39.5	42.7	45.9	49.2	52.5	55.8	59.1	62.3
20	65.6	68.9	72.2	75.5	78.7	82.0	85.3	88.6	91.9	95.1
30	98.4	101.7	105.0	108.3	111.5	114.8	118.1	121.4	124.7	128.0
40	131.2	134.5	137.8	141.1	144.4	147.6	150.9	154.2	157.5	160.8
50	164.0	167.3	170.6	173.9	177.2	180.4	183.7	187.0	190.3	193.6
60	196.8	200.1	203.4	206.7	210.0	213.3	216.5	219.8	223.1	226.4
70	229.7	232.9	236.2	239.5	242.8	246.1	249.3	252.6	255.9	259.2
80	262.5	265.7	269.0	272.3	275.6	278.9	282.2	285.4	288.7	292.0
90	295.3	298.6	301.8	305.1	308.4	311.7	315.0	318.2	321.5	324.8
100	328.1	331.4	334.6	337.9	341.2	344.5	347.8	351.0	354.3	357.6
110	360.9	364.2	367.5	370.7	374.0	377.3	380.6	383.9	387.1	390.4
120	393.7	397.0	400.3	403.5	406.8	410.1	413.4	416.7	419.9	423.2
130	426.5	429.8	433.1	436.4	439.6	442.9	446.2	449.5	452.8	456.0
140	459.3	462.6	465.9	469.2	472.4	475.7	479.0	482.3	485.6	488.8
150	492.1	495.4	498.7	502.0	505.2	508.5	511.8	515.1	518.4	521.7
160	524.9	528.2	531.5	534.8	538.1	541.3	544.6	547.9	551.2	554.5
170	557.7	561.0	564.3	567.6	570.9	574.1	577.4	580.7	584.0	587.3
180	590.5	593.8	597.1	600.4	603.7	607.0	610.2	613.5	616.8	620.1
190	623.4	626.6	629.9	633.2	636.5	639.8	643.0	646.3	649.6	652.9
200	656.2	659.4	662.7	666.0	669.3	672.6	675.9	679.1	682.4	685.7
210	689.0	692.3	695.5	698.8	702.1	705.4	708.7	711.9	715.2	718.5
220	721.8	725.1	728.3	731.6	734.9	738.2	741.5	744.7	748.0	751.3
230	754.6	757.9	761.2	764.4	767.7	771.0	774.3	777.6	780.8	784.1
240	787.4	790.7	794.0	797.2	800.5	803.8	807.1	810.4	813.6	816.9
250	820.2	823.5	826.8	830.1	833.3	836.6	839.9	843.2	846.5	849.7
260	853.0	856.3	859.6	862.9	866.1	869.4	872.7	876.0	879.3	882.5
270	885.8	889.1	892.4	895.7	898.9	902.2	905.5	908.8	912.1	915.4
280	918.6	921.9	925.2	928.5	931.8	935.0	938.3	941.6	944.9	948.2
290	951.4	954.7	958.0	961.3	964.6	967.8	971.1	974.4	977.7	981.0

Meters	00	10	20	30	40	50	60	70	80	90
300	984.2	1,017.1	1,049.9	1,082.7	1,115.5	1,148.3	1,181.1	1,213.9	1,246.7	1,279.5
400	1,312.3	1,345.1	1,377.9	1,410.8	1,443.6	1,476.4	1,509.2	1,542.0	1,574.8	1,607.6
500	1,640.4	1,673.2	1,706.0	1,738.8	1,771.6	1,804.5	1,837.3	1,870.1	1,902.9	1,935.7
600	1,968.5	2,001.3	2,034.1	2,066.9	2,099.7	2,132.5	2,165.3	2,198.2	2,231.0	2,263.8
700	2,296.6	2,329.4	2,362.2	2,395.0	2,427.8	2,460.6	2,493.4	2,526.2	2,559.0	2,591.9
800	2,624.7	2,657.5	2,690.3	2,723.1	2,755.9	2,788.7	2,821.5	2,854.3	2,887.1	2,919.9
900	2,952.7	2,985.6	3,018.4	3,051.2	3,084.0	3,116.8	3,149.6	3,182.4	3,215.2	3,248.0

Meters	000	100	200	300	400	500	600	700	800	900
1,000	3,281	3,609	3,937	4,265	4,593	4,921	5,249	5,577	5,905	6,234
2,000	6,562	6,980	7,218	7,546	7,874	8,202	8,530	8,858	9,186	9,514
3,000	9,842	10,171	10,499	10,827	11,155	11,483	11,811	12,139	12,467	12,795
4,000	13,123	13,451	13,779	14,108	14,436	14,764	15,092	15,420	15,748	16,076
5,000	16,404	16,732	17,060	17,388	17,716	18,045	18,373	18,701	19,028	19,357
6,000	19,685	20,013	20,341	20,669	20,997	21,325	21,653	21,982	22,310	22,638
7,000	22,966	23,294	23,622	23,950	24,278	24,606	24,934	25,262	25,590	25,919
8,000	26,247	26,575	26,903	27,231	27,559	27,887	28,215	28,543	28,871	29,199
9,000	29,527	29,856	30,184	30,512	30,840	31,168	31,496	31,824	32,152	32,480

The *actual* heights of constant-pressure surfaces are determined from a radiosonde sounding. We will use the following sounding to compute a few d-values:

TTAA 78001 72409 99030 05050 09015 00211 06060 09005 85490 00646 07016 70010 06900 08527 50560 22764 09047 40718 33372 09045 30916 459// 09071 25090 543// 09096 20255 581// 09099 15475 595// 09615 10745 575// 09100 88225 589// 09098 77132 09628 40508

Remember, with the exception of the 1,000-millibar level, the heights of constant-pressure surfaces encoded in the radiosonde code do not contain all the digits. Digits are added as follows:

- Prefix a "1" to the encoded 850-millibar height.

- Prefix a "2" or "3" to the height of the 700-millibar level. A "2" is prefixed if the first digit is "5" or greater, while a "3" is prefixed if the first digit is less than "5".

- Suffix a "0" to the height of the 500-, 400-, and 300-millibar levels.

- For levels 250 millibars or less, prefix a "1" and suffix a "0".

The procedure for computing the d-value for a constant pressure surface is as follows:

1. Find the encoded height of the constant-pressure level.
2. Add the proper prefix and/or suffix to the encoded value.
3. Convert the height value in meters into feet. (Use conversion table 6-1-7.)
4. Find the standard height of the constant-pressure level.
5. Use the formula $D = Z_A - Z_S$ or determine the difference between the actual height and the standard height. If the actual height is higher than the standard height, prefix the value with a plus (+) sign. If the actual height is lower than the standard height, prefix the difference with a minus (−) sign.

Using the following steps, we can now compute the d-value for the 850-millibar level found in the above sounding.

1. The height of the 850-millibar level is encoded as 490.
2. To get the actual height of the level, we must prefix the encoded value with a "1." The actual height is 1,490 meters.
3. 1,490 meters converts to 4,889 feet from the table.
4. The standard height of the 850-millibar level is 4,781 feet.
5. The difference between the actual height and the standard height is 108 feet. Because the actual height is greater than the height of the standard level, the d-value is +108 feet.

Learning Objective: Identify the three types of condensation trails, and recognize how they form.

CONDENSATION TRAILS

A condensation trail (*contrail*) is a visible trail of small water droplets or ice crystals formed under certain conditions in the wake of an aircraft.

The formation of contrails is considered to decrease significantly the effectiveness of operational aircraft under combat conditions. In daylight when clear weather prevails, the problem of detecting the enemy is practically solved. When the aircraft produces contrails at night, the contrails greatly simplify the enemy-interception problem.

To remove the detection hazard during combat missions, predicting the altitudes at which contrail formation is probable is necessary so that flight at those altitudes may be avoided. Such prediction is a function of the weather office that provides the briefing for the flight.

Types of Contrails

There are three types of contrails: aerodynamic, instability, and engine exhaust.

The aerodynamic contrail is produced by the momentary reduction of pressure resulting from the flow of air past an airfoil. Since it is of short duration, it is not considered an operational hazard.

The instability contrail is produced by the passage of an aircraft through an otherwise undisturbed layer of unstable air with a higher relative humidity. Conditions conducive to such formations exist only rarely.

Entrainment

Entrained air is that which is drawn into and mixed with the exhaust gases of the aircraft. The amount of air entrained into the exhaust trail varies continuously from near zero immediately behind the aircraft to an extremely large amount far behind it. The rate at which air is entrained varies with the type of aircraft, power setting, speed, and the density and stability of the atmosphere. The ratio of entrained air to exhaust gas at a given distance behind the aircraft is greatest when the aircraft is operating at its most efficient speed and altitude.

Meteorological Factors

If the temperature, pressure, and humidity are suitable, the water vapor of the exhaust may produce supersaturation with consequent contrail formation. The more humid the air at a given temperature and pressure, the greater the tendency for contrails to form.

NOTE: Only in the case of jet aircraft can a definite relationship be established between pressure, temperature, and relative humidity. In propeller-driven aircraft, energy losses are variable. Since all of the energy is not contributed to the wake, only an estimate of the limiting temperatures for contrail formation can be given.

UNIT 6—LESSON 2

ANALYZING THE SKEW T, LOG P DIAGRAM

OVERVIEW	OUTLINE
Identify parameters on the Skew T, Log P Diagram.	Skew T parameters Dry adiabats Saturation adiabats Saturation mixing ratio Thickness scale Contrail formation curves U.S. Standard Atmosphere
Describe the computation procedure to find derived measurements from plotted data on the Skew T.	Computation of derived measurements Potential temperature Frost point temperature Saturation mixing ratio Actual mixing ratio Relative humidity Wet-bulb temperature Wet-bulb potential temperature Virtual temperature Layer thickness Freezing level
Describe the computation procedure to find the forecast surface temperatures on the Skew T.	Temperature computations Maximum temperature Minimum temperature
Define and describe computation procedures for cloud formation parameter analysis on the Skew T.	Computation of cloud formation parameters on the Skew T Lifting condensation level (LCL) Convective condensation level (CCL) Mixing condensation level (MCL) Level of free convection (LFC) Positive energy area (PEA) and negative energy area (NEA) Equilibrium level (EL)

OVERWIEW	OUTLINE
Identify the criteria used in cloud layer analysis on the Skew T.	Cloud layer criteria Cloud layer analysis Cloud type analysis
Define the use of and describe the computation procedures for commonly used stability indices on the Skew T.	Computation of stability indices on the Skew T Showalter Stability Index (SSI) Lifted Index (LI) K-Index (KI) Total Totals Index (TT)
Describe the computation procedures for convective activity forecast guides on the Skew T.	Computation of convective activity forecast guides on the Skew T Thunderstorm gusts (T_1 and T_2 methods) Convective turbulence Hail occurrence Hail size
Describe the computation procedure for contrail formation analysis on the Skew T.	Computation of contrail formation on the Skew T
Describe the computation procedures for icing-level analysis on the Skew T.	Icing computations on the Skew T Minus 8D icing analysis Maximum icing intensity analysis
Determine how the Skew T may be used to analyze weather fronts.	Frontal analysis on the Skew T

ANALYZING THE SKEW T, LOG P DIAGRAM

The Skew T, Log P Diagram is a thermodynamic diagram on which information obtained from upper-air soundings is plotted and analyzed. Several procedures have been developed that allow rapid graphical computations from data plotted on a Skew T chart. In this lesson we explain the more important parameters of the Skew T diagram, and then cover the more frequently used computations that you will need to know to analyze the Skew T. These procedures include computations of derived measurements, cloud formation parameters, expected temperatures, cloud layer criteria, convective weather guidelines, indices for severe weather, contrail formation guidelines, the freezing level, and icing. We will also discuss frontal analysis on the Skew T. Before going on, you should review Unit 3 - Lesson 3 of the *AG3* training manual for plotting procedures and *AG2, Volume 2,* Unit 2 - Lesson 4, for stability theory. Note: The figures referred to in the text are in black and white, while the Skew T diagram is printed in black, brown, light green, and dark green. You may wish to obtain an actual Skew T, Log P Diagram (DOD WPC 9-16) in order to follow the text more accurately.

Learning Objective: Identify parameters of the Skew T, Log P Diagram.

SKEW T PARAMETERS

The Skew T diagram represents a graphical presentation of the relationship between many

parameters in the thermodynamic equation. In the *AG3* manual you studied the isobars, isotherms, height scales, and wind scale, while learning to plot the temperature curve, dew point curve, pressure altitude curve, and wind reports. Now you need to learn what the other lines are and how to use them.

Dry Adiabats

The *dry adiabats* represent the rate at which nonsaturated air will cool as it moves upward, or warm as it moves downward in the atmosphere. This rate of cooling or warming is called the dry adiabatic lapse rate. On the diagram, the dry adiabats are drawn as thin, slightly curved brown lines extending diagonally upward from right to left. These lines have a spacing, or interval, of 2 °C, and are labeled across the top, bottom, and along the sides of the chart in diagonal bold brown numbers. The light brown numbers within parentheses below the bold numbers at the top of the diagram are the values for the dry adiabats in the 100- to 25-millibar pressure range. The values of the dry adiabats and the isotherms are the same at the 1,000-millibar level. These values represent potential temperature in degrees Celsius.

Saturation Adiabats

The *saturation adiabats* are the curved green lines that intersect the 1,000-millibar isobar at 2 °C intervals. These lines curve upward toward the left and diverge as they get closer to the top of the diagram. They terminate at the 200-millibar level and are labeled at that point in green numbers. The values can also be read at the 1,000-millibar level, where they are the same as the value of the intersecting isotherms. These lines represent the rate at which a saturated parcel of air will cool as it moves upward in the atmosphere. Saturated air will not warm at this rate as it moves downward in the atmosphere, because it will become nonsaturated the moment it begins to descend and the pressure increases. The difference in the dry adiabatic and saturation adiabatic lapse rates is the *heat of condensation* gained by the air when water vapor condenses out of saturated air as it is lifted.

Saturation Mixing Ratio

The dashed green lines extending from the bottom of the diagram upward diagonally toward the right are the *saturation mixing ratio* lines. They are labeled near the bottom of the diagram in green numbers representing grams of water per kilogram of air. We use the mixing ratio lines later to find how much moisture is in the air (actual mixing ratio) and how much moisture the air can hold (saturation mixing ratio).

Thickness Scale

Ten horizontal scales printed in black extend across the central portion of the diagram parallel to the isobars. These are the thickness scales. Each is labeled on the left side by two numbers separated by a solidus, such as the 1000/700 we find on the bottommost scale near the 840-millibar isobar. They are graduated, with increments being in feet above the horizontal line and in meters below the horizontal line. The graduations are labeled in hundreds of feet and in hundreds of meters. These scales are used to calculate the thickness of the layer of the atmosphere between the two values. We would use the bottom scale to calculate the thickness of the 1,000-millibar to 700-millibar layer, for instance.

Contrail Formation Scale

At the 500-millibar isobar between the −36 degree and −47 degree isotherms are four fine black lines extending upward to the right all the way to the top of the diagram. At the 400-millibar isobar (which is also the 100-millibar isobar) are four dashed black lines extending upward to the right, ending at the 40-millibar level. These are the *contrail formation scales* for the 500-millibar to 100-millibar and 100-millibar to 40-millibar levels. They are labeled from right to left as 100, 90, 60, and 0. The lines indicate the temperature and relative humidity necessary at any pressure above 500 millibars for saturation to occur by the addition of water vapor from a jet aircraft engine. We will use these scales to analyze contrail formation levels.

U.S. Standard Atmosphere

The *U.S. Standard Atmosphere* is a representation of an ideal atmosphere based on the thermodynamic equation and the defined standards for sea level pressure (29.921 inches of mercury) and sea level temperature (59.0 °F). It is <u>not</u> a climatological average for the continental United States. The temperatures of the standard atmosphere are plotted as a single brown line extending from the bottom of the chart

at the 17 °C isotherm upward to the left to 256 millibars, then along the −56.5 °C isotherm to the 100-millibar level. Standard heights are printed in both meters and feet on the left side of the diagram under the standard pressure levels, as well as on a scale to the right of the diagram.

Learning Objective: Describe the computation procedure to find derived measurements from plotted data on the Skew T, Log P Diagram.

COMPUTATION OF DERIVED MEASUREMENTS

Now that you understand what all those strange looking lines represent, we can use the plotted temperature, dew point, and height data to find some additional data measurements. This data normally would be calculated using complex formulas from the reported data. On the Skew T, we simply follow the correct lines to find the values. We will derive measurements for the potential temperature, frost point temperature, saturation mixing ratio, actual mixing ratio, relative humidity, wet-bulb temperature, wet-bulb potential temperature, virtual temperature, and layer thickness in this manner.

Potential Temperature

Potential temperature (θ) is the temperature a parcel of air can attain if it descends dry adiabatically to the 1,000-millibar level. Since the dry adiabats are labeled in degrees Celsius and coincide with the isotherms at the 1,000-millibar level, we can see that the dry adiabats actually are potential temperature lines. To find the potential temperature of a parcel of air, interpolate the value of the plotted temperature by using the dry adiabats closest to the temperature plot. You may find it easier to read the value by drawing a light pencil line parallel to the dry adiabats either upward to the top of the diagram where the values are printed or downward to the 1,000-millibar level and reading the isotherm value.

Frost Point Temperature

Frost point is the temperature to which air has to be cooled to reach saturation with respect to ice. The frost point is always warmer than the dew point below zero degrees Celsius. An approximation of the frost point temperature may be made using the formula

$$T_F = \frac{9}{10} T_D,$$

where T_F = frost point temperature and T_D = dew point temperature.

While this formula does not yield an exact frost point temperature, it is quickly and easily computed. See figure 6-2-1.

The frost point temperature should be computed and plotted for all levels above the point where the air temperature crosses the 0 °C isotherm. This is especially important when analyzing the Skew T for cloud layers. The frost point curve will fall between the temperature and the dew point curve unless the cloud is supersaturated with respect to ice. In this case, the frost point curve will cross to the right of the temperature curve.

In clouds with temperatures above freezing, the true dew point will coincide closely with the true temperature, indicating that the air between the cloud droplets is practically saturated with respect to the water surface of the droplets. Minor discrepancies may exist when the cloud is not in a state of equilibrium (when the cloud is forming

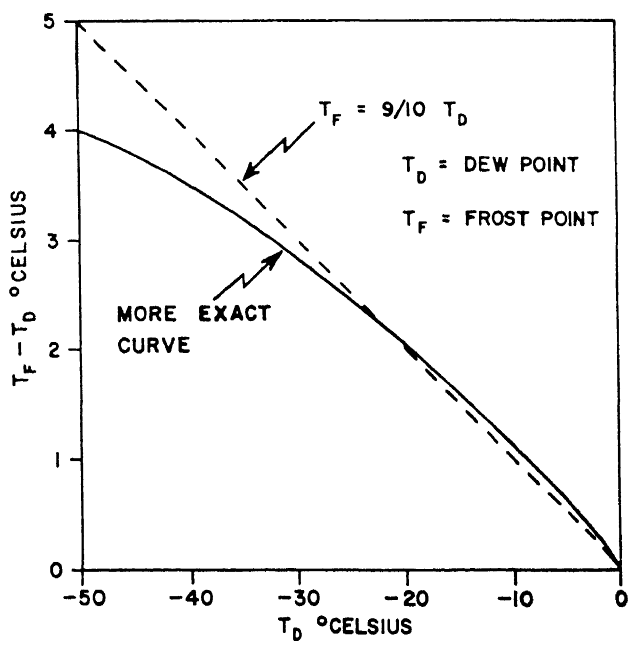

Figure 6-2-1.—Frost point temperature comparison.

or dissolving rapidly), or when precipitation is falling through the cloud with temperatures slightly different from the air temperature. These differences are small theoretically. In the subfreezing part of the cloud, the true temperature at which condensation occurs will fall between the frost point temperature and the dew point temperature. If the cloud consists entirely of supercooled water droplets, this temperature will be the same as the dew point temperature. If the cloud is made entirely of ice crystals, the frost point will coincide with the true condensation temperature, which means that the moisture is changing directly from water vapor into ice crystals through sublimation. Below −12 °C, most clouds form through the sublimation of water vapor directly into ice crystals.

We may state, as a general rule, that clouds below −12 °C are saturated with respect to ice; therefore, the moisture content should be evaluated by use of the frost point temperature. Above freezing, clouds are generally saturated with respect to water, and the dew point temperature should be used to evaluate the moisture content. Between the freezing point and −12 °C, clouds may be saturated with respect to water or to ice, or somewhere between the two values if a cloud is mixed ice and water. In the last case, the moisture content should be evaluated using both the dew point and frost point temperatures. Supersaturation with respect to ice, as indicated by the frost point temperature being greater than the air temperature, will indicate a mixed cloud or a supercooled water cloud.

Saturation Mixing Ratio

Saturation mixing ratio (W_S) is the theoretical maximum amount of water vapor that air at a specific temperature and pressure can hold. When air is saturated, it cannot hold any additional water vapor. To find this value at any pressure level, use the dashed green saturation mixing ratio lines on either side of your plotted temperature. Interpolate the value of your temperature plot using the scale on the mixing ratio lines printed just above the 1,000-millibar level. For instance, if your 500-millibar temperature is −15.6 °C, this falls halfway between the green dashed lines labeled 2.5 and 2.0, you would interpolate the value to be 2.25. Since these lines represent grams of water per kilogram of air, you know that a parcel of saturated air with a pressure of 500 millibars and a temperature of 15.6 °C can hold 2.25 grams of water vapor per kilogram of air.

Actual Mixing Ratio

To find the *actual mixing ratio* (W), often called simply the mixing ratio, interpolate the value of the same dashed green lines at the plotted dew point temperature for temperatures above freezing and down to −12 °C. For levels where the air temperature is below freezing, evaluate the value of the mixing ratio line through your calculated frost point temperature. You will have two sets of values in the 0 °C to −12 °C range. For levels where the air temperature is below −12 °C, you need only evaluate the mixing ratio through the frost point temperature. When we do this, we find how much water vapor is held by a parcel of air at the specified pressure level. For example, if your 800-millibar temperature is 5.0 °C and your dew point temperature is 3.0 °C, you should read the value of your mixing ratio line through the dew point temperature as 6.0 grams of water per kilogram of dry air (or simply 6.0 g/kg). But let's look at a case where your temperature is between 0 °C and −12 °C. Say your 600-millibar temperature is −10.0 °C and the dew point temperature is −15.0 °C. You should first calculate a frost point temperature. In this case, it is −13.5 °C. Now evaluate the mixing ratio through both the dew point temperature and the frost point temperature. You should find a value of 2.0 g/kg for the dew point temperature and 2.25 g/kg for the frost point temperature. In the next section we will use this same example to highlight the difference between the two values of the actual mixing ratio.

Now that you know how to find the saturation mixing ratio and the actual mixing ratio, what do you do with them? Let's find out.

Relative Humidity

Relative humidity is a ratio, expressed in percent, of the amount of water vapor in the air (actual mixing ratio) compared to the amount of water vapor the air can hold (saturation mixing ratio). Since we have already found these values, we can find the relative humidity for any plotted pressure level by using the formula

$$RH = \frac{W}{W_S} \times 100,$$

where RH = relative humidity, in percent;

W = actual mixing ratio; and

W_S = saturation mixing ratio.

Since the units (grams per kilogram) cancel, we are left with a number, expressed as a percentage.

Wet-bulb Temperature

Wet-bulb temperature (T_W) is the lowest temperature to which air can be cooled by the evaporation of water into the air at a constant pressure. Of course, the heat required for evaporation is supplied by the air. This is called the *heat of vaporization*. During this process, the air is cooled. The wet-bulb temperature is found by a graphical process on the Skew T, as follows:

1. From the dew point temperature, draw a line upward parallel to the mixing ratio lines.
2. From the temperature, draw a line upward parallel to the dry adiabats.
3. From the point where these two lines intersect, draw a line downward parallel to the moist adiabats to intersect the original pressure level. The temperature at the point of intersection is the wet-bulb temperature. See figure 6-2-2 for an example of the wet-bulb temperature procedure.

When constructing a wet-bulb-temperature curve, plot the wet-bulb temperatures in green. You may evaluate all plotted pressure levels up to the dew point cutoff, then connect the wet-bulb temperatures by a green line to draw the curve. In practice, the *Wet-bulb-Zero* (WBZ) height is the only data routinely used. The WBZ is the level at which the wet-bulb temperature crosses the 0 °C isotherm. This can be found by constructing the wet-bulb curve only in the area where the temperature and dew point traces cross the 0 °C isotherm.

Wet-bulb Potential Temperature

Wet-bulb potential temperature (T_θ) is the wet-bulb temperature a parcel of air would have if the parcel descended to 1,000 millibars. To find the wet-bulb potential temperature, simply read the values for the closest saturation adiabats. You may find it easier to read the values by drawing a light pencil line from the wet-bulb temperature parallel to the saturation adiabats to either the 1,000-millibar level or the 200-millibar level. Interpolate if necessary. See figure 6-2-2 for an example.

Virtual Temperature

Virtual temperature (T_V) of a parcel of air is a *derived* value based on the air temperature and the water content of the air. The virtual temperature can be approximated by the formula

$$T_V = T + \frac{W}{6},$$

where T_V = virtual temperature at a pressure level,

T = temperature at the pressure level, and

W = actual mixing ratio at the pressure level.

For example, suppose we have a plotted report at 700 millibars with a temperature of −5 °C and a dew point temperature of −7.9 °C. Reading the mixing ratio at the dew point temperature would give us an actual mixing ratio (W) of 3.0 grams per kilogram. Using the formula, we would find the following:

$$T_V = T + \frac{W}{6}$$

$$T_V = -5\,°\mathrm{C} + \frac{3\ \mathrm{g/kg}}{6\ \mathrm{g/kg}}$$

$$T_V = -4.5\,°\mathrm{C}$$

Repeating these calculations for all temperature levels, plotting the values in pencil, and connecting the plots will yield a virtual temperature curve. If plotted, this curve will always be to the right of the actual temperature curve. Where the air is dry, the virtual temperature curve will be plotted just about over the actual temperature curve.

In most work done on the Skew T, the <u>actual temperature</u> curve is used. But in cases where air density is a factor, such as in stability and thickness computations, the <u>virtual temperature</u> curve should be used.

Layer Thickness Computation

Layer thickness, or the depth through a layer, is used by the forecaster to determine the type of precipitation expected, as well as several other forecast evaluations. The thickness of a layer is a function of the temperature and the moisture content. The warmer the air through a layer, the thicker the layer. The thickness scales are printed

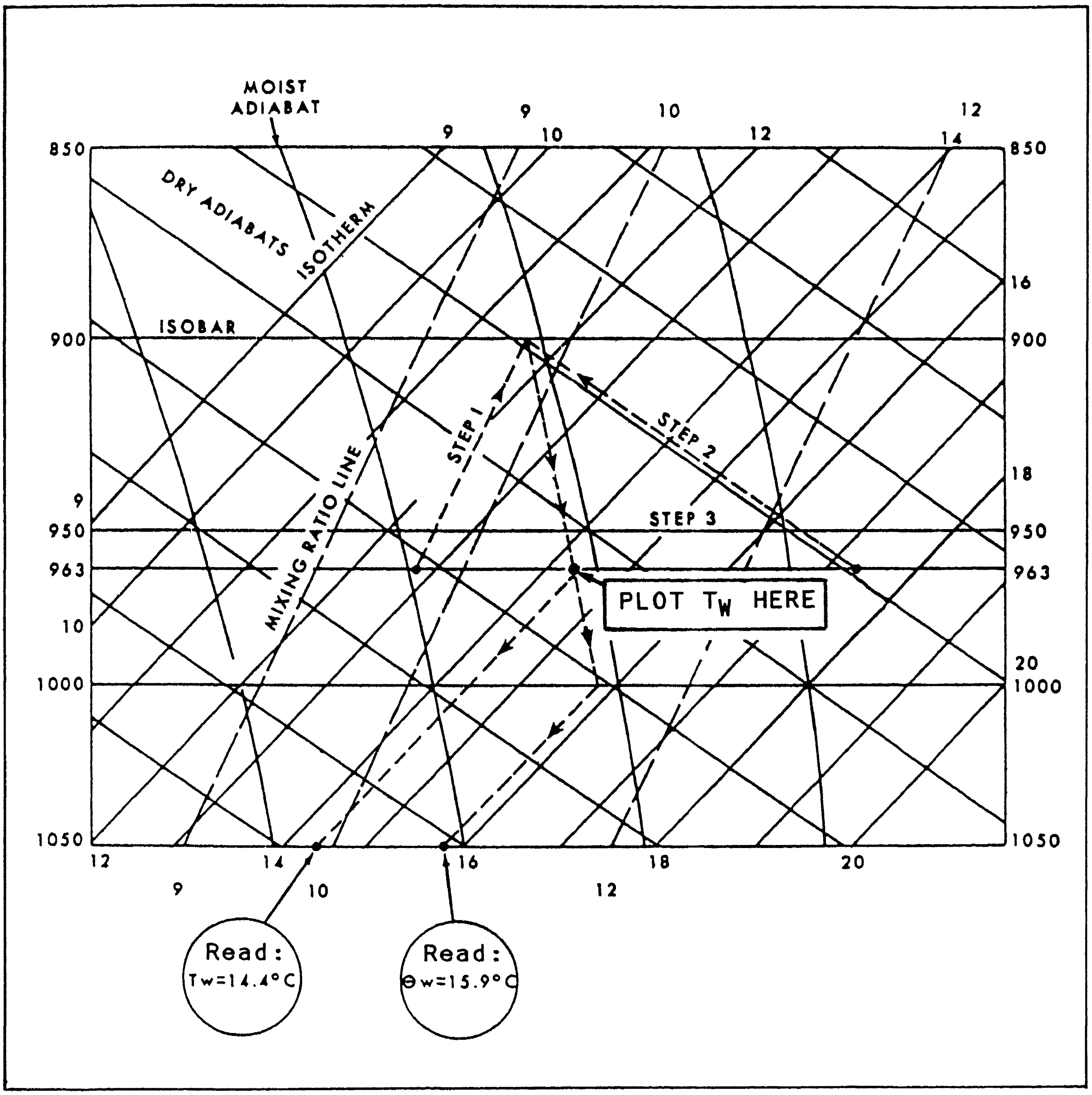

Figure 6-2-2.—Wet-bulb temperature and potential temperature.

on the Skew T for the standard layers routinely evaluated. To compute layer thickness on a plotted Skew T, follow these steps:

1. Determine if the dew point curve through the layer indicates an average moisture greater than 3 g/kg.

a. If the average moisture is greater than 3 g/kg, the virtual temperature curve should be constructed for the layer.

b. If the average moisture is less than 3 g/kg, the difference between the virtual temperature curve and the actual temperature curve will be very slight, and the actual temperature curve may be used in place of a virtual temperature curve.

2. Bisect the virtual temperature curve (or actual temperature curve) through the layer with a vertical line so the area enclosed by your vertical line, the upper and lower isobars, and the

temperature curve is approximately equal. See figure 6-2-3.

3. Read the layer thickness where your vertical line intersects the appropriate thickness scale.

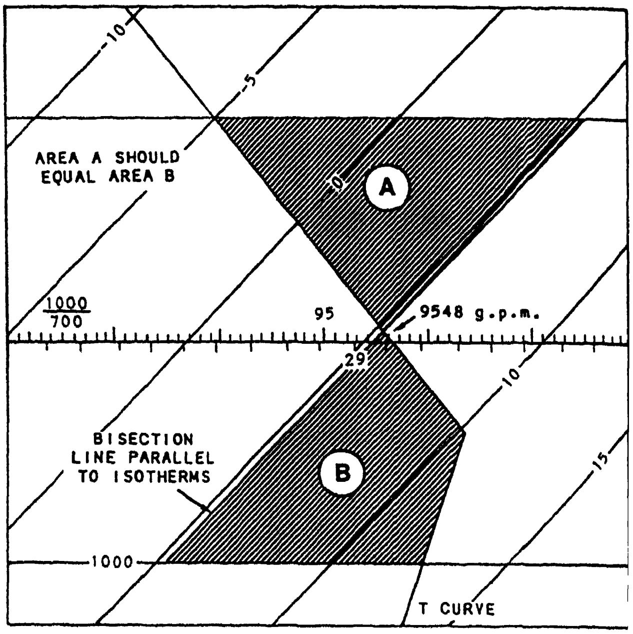

Figure 6-2-3.—Equal area bisection through a layer.

Freezing Level

Freezing level is the height, or heights, in the atmosphere where the temperature falls below the freezing point of water. Finding it is a fairly straightforward process. Follow the plotted temperature curve up until you intersect the 0 °C isotherm. If your temperature curve is progressing from warmer to colder temperatures, you have a freezing level. Determine the height of this pressure level using the pressure-altitude curve. There may be more than one freezing level above a station at any one time.

Learning Objective: Describe the computation procedure used to find the forecast surface temperatures on the Skew T.

COMPUTATION OF PREDICTED SURFACE TEMPERATURES ON THE SKEW T

While forecasting maximum and minimum temperatures for your station or location is obviously a job for the forecaster, proper analysis of the Skew T may give the forecaster a computed value for both the expected maximum and the expected minimum temperatures. Forecasters commonly use these computed values as one of several inputs for their temperature forecast. A major limitation of both techniques that we will discuss is that they are only valid for predicting the temperature within an air mass. If a frontal passage is expected between the time of the morning sounding and the time of the expected maximum temperature that afternoon or the time of the expected minimum temperature the following morning, these techniques should not be used. Another limitation is that the forecaster should routinely forecast temperatures out to 48 hours for any location and out to 5 days for stateside locations, while these techniques only provide predictions out to 24 hours.

Maximum Temperature

Calculations for the maximum temperature on the Skew T should be done using the early morning, or cool, sounding for the day. For continental United States locations, this is normally done with the 1200Z plotted on a Skew T. Of course, many of us are not stationed in CONUS, and we have to use the available sounding that comes closest to the coolest part of the day, during the period near sunrise. In order to calculate the maximum expected temperature for the day, you must first determine if the day will be cloudy, with little solar insolation received at the surface, or sunny, with a great deal of solar insolation received at the surface. Analysis of the current clouds and expected cloud development on the Skew T should provide this information, or consult the forecaster.

If the day is expected to be mostly sunny, follow a dry adiabat from your 850-millibar temperature to the surface pressure level and read the temperature at the intersection. For mountainous areas and high elevations, you

should adjust the procedure to start at a pressure level about 5,000 feet above the surface.

If the day is expected to be mostly cloudy (broken cloud cover to overcast), follow a saturation adiabat from the 850-millibar level (or 5,000-foot AGL pressure level) to the surface pressure level and read the temperature at the intersection. See figure 6-2-4 for examples of the maximum temperature computations for sunny and cloudy conditions.

In summer air mass situations, strong radiation inversions routinely develop. If your plotted morning Skew T shows a radiation inversion with a top between 4,000 and 6,000 feet, you should use the temperature at the top of the inversion (the warmest point in the inversion) as the starting point in the computation, instead of the 850-millibar temperature.

Minimum Temperature

Minimum temperature computations on the Skew T are not as reliable as maximum temperature computations on the Skew T. Many locations have developed methods using the Skew T that work well at one location but are not even close for a different location. Use locally derived procedures for your station if available. Otherwise, two methods for calculating minimum temperatures work fairly well at many locations. You may use either or both methods to find at least a ballpark value for the expected minimum temperature.

The first method uses the early morning sounding to predict a minimum temperature for the following morning. Essentially, this is a 24-hour forecast. From the 850-millibar dew point

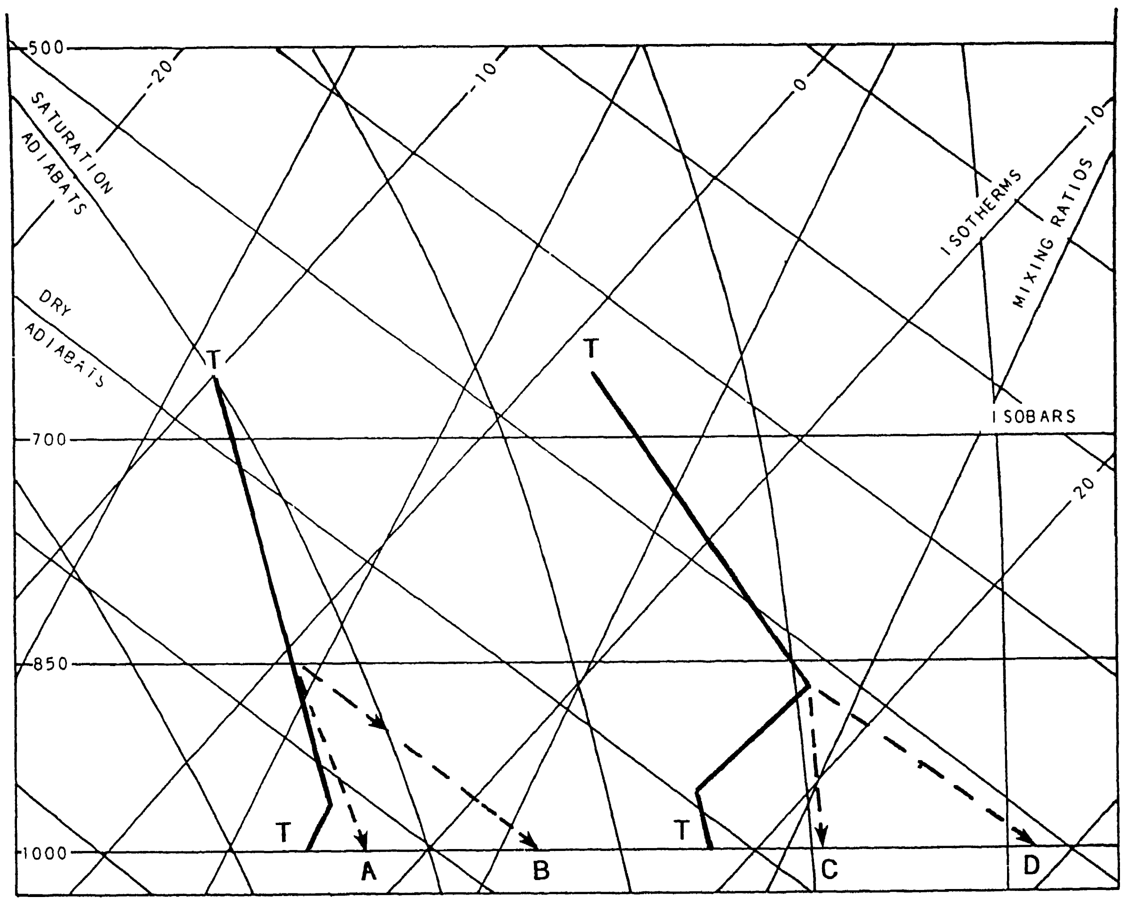

Figure 6-2-4.—Computation of maximum temperature; with no inversion 4,000 to 6,000 feet and (A) mostly cloudy skies (B) mostly clear skies; with an inversion between 4,000 to 6,000 feet and (C) mostly cloudy skies (D) mostly clear skies.

temperature, follow a saturation adiabat to the current surface pressure level and read the temperature. An example is shown in figure 6-2-5. The write-up on this procedure does not mention an adjustment for high elevations, but if you are stationed at a high elevation, you may wish to experiment by using the dew point temperature at 5,000 feet.

A second technique does not actually require the use of the Skew T, although an afternoon sounding conducted near or at the time of maximum heating may be used. In this technique, the dew point temperature at the time of maximum heating is used as the estimate for the minimum temperature the following morning.

We have just briefly described two procedures that may be used on the Skew T to compute maximum and minimum temperatures. I must stress that these values are just one input for a proper and accurate temperature forecast, and should not be used without careful forecaster consideration of climatology, numerical forecasts, advection, and other important atmospheric modifiers, which you will study in *AG1&C*.

Learning Objective: Define the use of and describe the computation procedures for cloud formation parameter analysis on the Skew T, Log P Diagram.

COMPUTATION OF CLOUD FORMATION PARAMETERS

Several graphical and mathematical computations using the data plotted on a Skew T will let

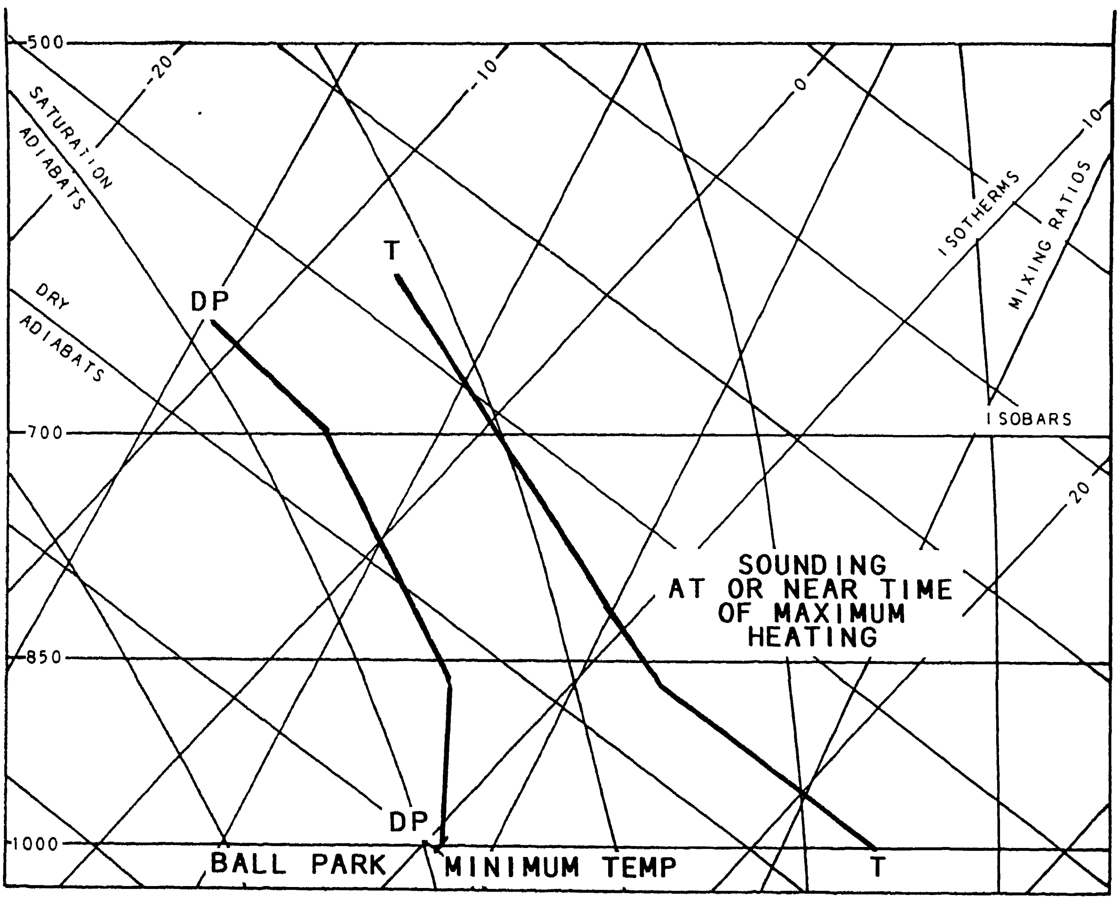

Figure 6-2-5.—Computation of minimum temperature.

us determine where clouds may form if certain conditions are met. In this section, we will look at the levels where we may expect cloud bases to form and the levels where we expect them to end.

Lifting Condensation Level (LCL)

Lifting Condensation Level (LCL) is the height at which a parcel of moist air becomes saturated when "lifted" dry adiabatically. The lifting is brought about by air being forced up (lifted over) frontal and orographic (hilly and mountainous) surfaces. Use this level for your estimate of cloud bases caused by mechanical lifting.

LCL is computed using the surface temperature and dew point. The computation is as follows:

1. From the surface temperature, draw a line upwards parallel to the closest dry adiabat.
2. From the surface dew point, draw a line upwards parallel to the nearest mixing-ratio line.
3. LCL is found at the point of intersection of the two lines. See figure 6-2-6.

Convective Condensation Level (CCL) and Convective Temperature (CT)

Convective Condensation Level (CCL) is the height at which a parcel of air, when heated sufficiently from below, rises and becomes saturated. It is where newly forming convective clouds should form bases. There are two methods used to find CCL. One method uses the surface dew point to find CCL. This is known as the parcel method because it evaluates a parcel of air near the surface. It is commonly designated CCL_P. The second method evaluates CCL using the moist layer near the surface and is known as the moist-layer method, designated CCL_{ML}. The parcel method works well when predicting the bases of ordinary cumulus clouds, while the moist-layer method is preferred when predicting thunderstorms and associated phenomena. Both should be evaluated when analyzing the Skew T.

To determine CCL_P, draw a line upwards from the surface dew point parallel to the nearest saturation mixing ratio line until your line

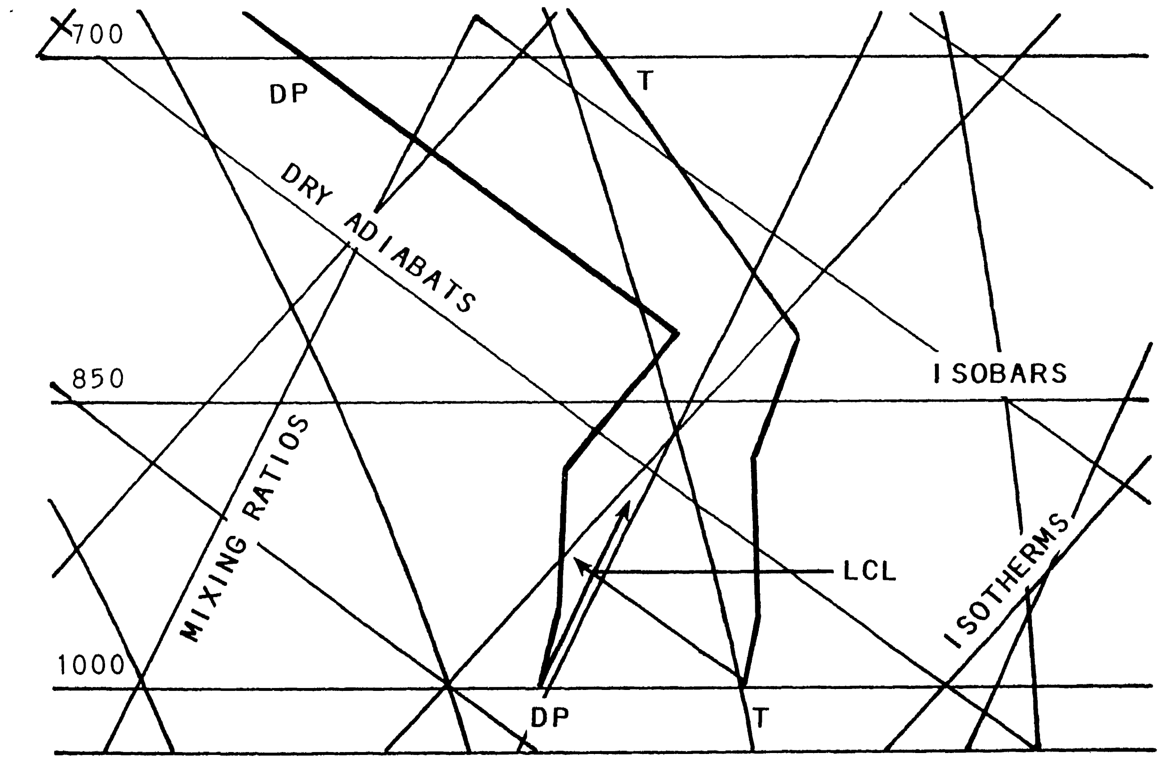

Figure 6-2-6.—Determination of the lifting condensation level.

intersects the plotted temperature curve. This is CCL_P. See figure 6-2-7.

Now that we have determined CCL_P, we can very quickly calculate the temperature the surface must reach if clouds are to form at CCL_P. This is the *Convective Temperature (parcel method)* (CT_P). Once a parcel of air near the surface has heated to this temperature, it will rise to its condensation level without ever being colder than the surrounding air. The CT is found by proceeding from CCL dry adiabatically to the surface. See figure 6-2-7.

Finding CCL_{ML} is a little more complex. Draw a light line parallel to the temperature curve 6 °C cooler than the temperatures on the lowest 150 millibars of your sounding. Your line represents a dew point depression roughly equivalent to 65 percent relative humidity. The area where the dew point curve is to the right of your line is considered a moist layer. Now, bisect the dew point curve in the moist layer, or the dew point curve in the lower 150 millibars if the moist layer exceeds the lower 150 millibars, with a mixing ratio line. The level where this mixing ratio line crosses the temperature curve is CCL_{ML}. See figure 6-2-8 for an example of CCL_{ML}. Note that in figure 6-2-7 insufficient moisture is present to find CCL_{ML}. When insufficient moisture is present, it should be noted in the analysis block of the Skew T. Although cumulus clouds may form during the day if the temperature increases sufficiently, there is not enough moisture present to form cumulonimbus clouds.

Following the dry adiabat to the surface from CCL_{ML} and reading the temperature will give us the *Convective Temperature (mixed layer method)* (CT_{ML}).

We have discussed where clouds may form due to mechanical lift or heating. Now we will look at a situation where clouds may form even if we do not have a large amount of heating or some mechanical lift.

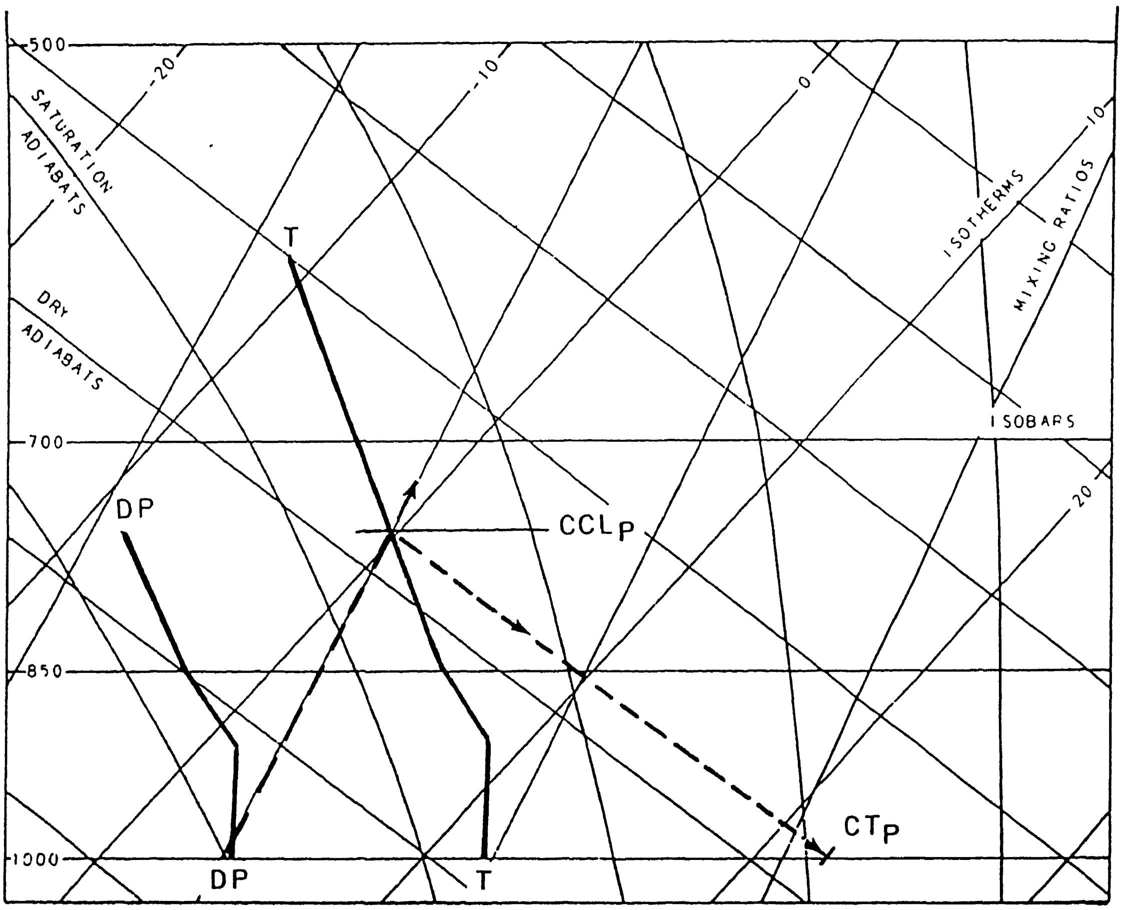

Figure 6-2-7.—Convective condensation level and convective temperature by the parcel method.

Mixing Condensation Level

Mixing Condensation Level (MCL) is the lowest height at which saturation may occur if the near surface layer is or will be mixed completely by wind action. You may relate this to a situation in which you have a radiation inversion keeping the boundary layer wind away from the surface. Mixing is occurring at the top of the inversion. When the radiation inversion breaks, the boundary winds will reach the surface, and mixing will take place through the layer formerly protected from the turbulent winds by the inversion. Before we proceed, let's look at what occurs in the atmosphere when mixing occurs, and how this is different from convection.

Mixing occurs in a layer when vertical wind speed shear or vertical direction wind shear occurs. As was discussed in the previous lesson, shear causes turbulence due to updrafts and downdrafts. These updrafts and downdrafts produce the mixing action.

When mixing occurs, the air in the downdrafts warms dry adiabatically; in an updraft it cools dry adiabatically until saturation is reached, then it cools saturation (moist) adiabatically. The air in the layer tends to become more unstable due to warming in the lower levels if saturation is reached within the layer. The moisture present in a layer tends to become evenly distributed through the mixed layer. The mean mixing ratio line through the layer before mixing closely approximates the dew point curve through a layer after mixing.

In the horizontal, we can expect to see relatively equal relative humidity percentages. In the convective-cloud formation process, we find columns of rising air that become saturated and form clouds. Relative humidity in a horizontal

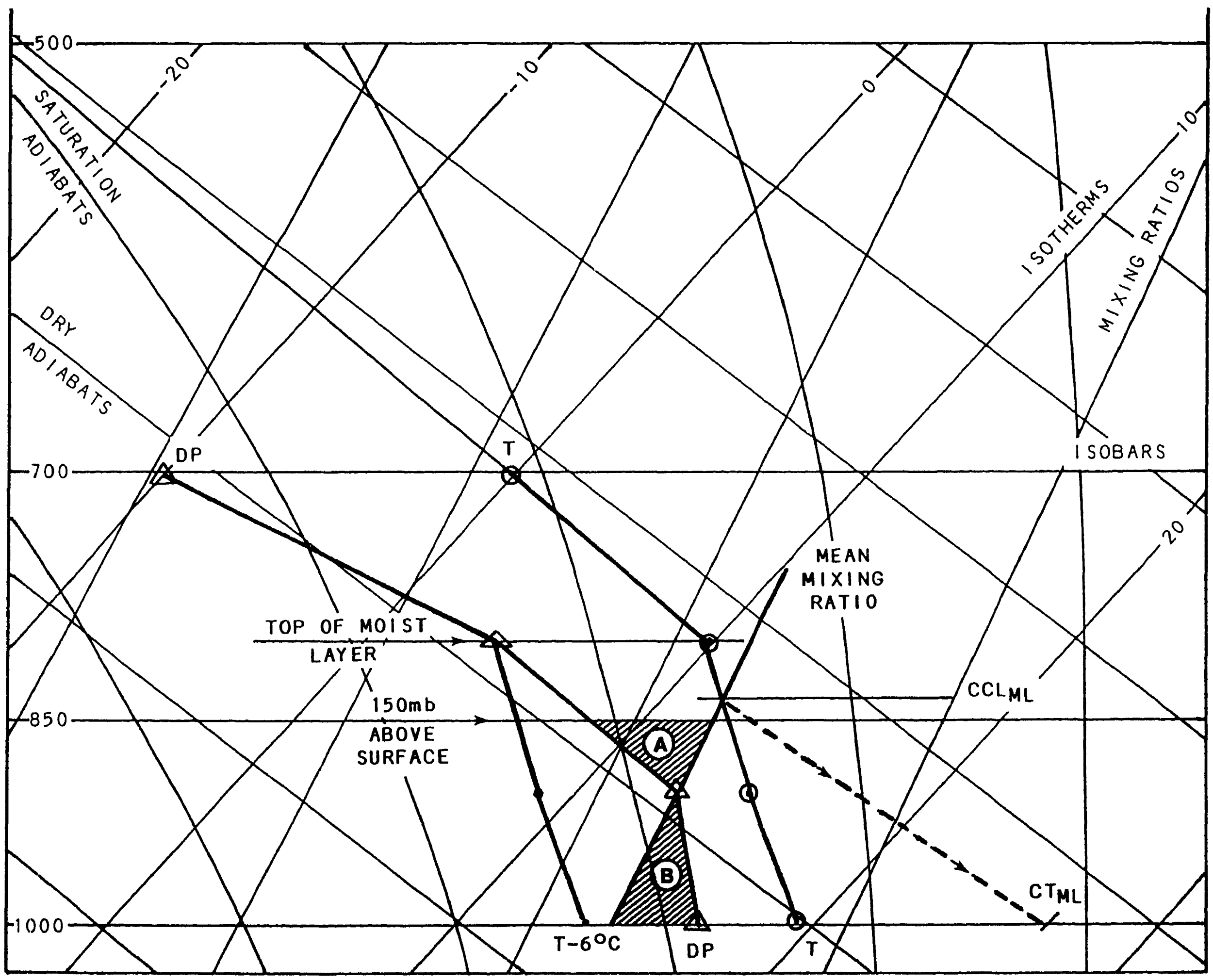

Figure 6-2-8.—Convective condensation level and convective temperature by the moist-layer method.

layer in this case would show large changes between cloud columns and the ambient air. Since the moisture in a mixed layer is evenly distributed throughout the layer, we do not expect to see scattered clouds forming. Instead, we expect saturation to be reached at the same level throughout the mixed layer. The turbulent process will cause small, relatively evenly spaced areas where downdrafts are occurring where the humidity is slightly lower. Because of this, clouds formed in mixing layers are strato-cumuloform. You will find that mixing layers, when approaching saturation, progress from clear skies to thin broken to overcast layers to dense overcast layers. Generally, no clouds will be evident in a mixed layer until the dew point or frost point depression decreases to less than 2.5 °C. Typically, the depression is less than 1.5 °C in observed cloud layers caused by mixing. This contradicts the general thumb rules for cloud coverage presented later in this lesson on cloud layer analysis.

Now that we understand what happens in a layer when mixing occurs, we can see that computation of a MCL on an analysis is useless. Mixing will not begin to occur in your air mass unless certain changes occur. The changes that need to occur for mixing to begin must be forecast. If the mixing process is expected because of increasing wind speeds with a frontal passage, the forecaster must first adjust the lower dew point and temperature curves to reflect the changes expected with frontal passage. If mixing is expected to occur after a radiation inversion breaks, the forecaster must first adjust the temperature curve to approximate the low level temperature at that time. In both cases, the forecaster will need to forecast changes in the vertical wind profile to determine the top of the

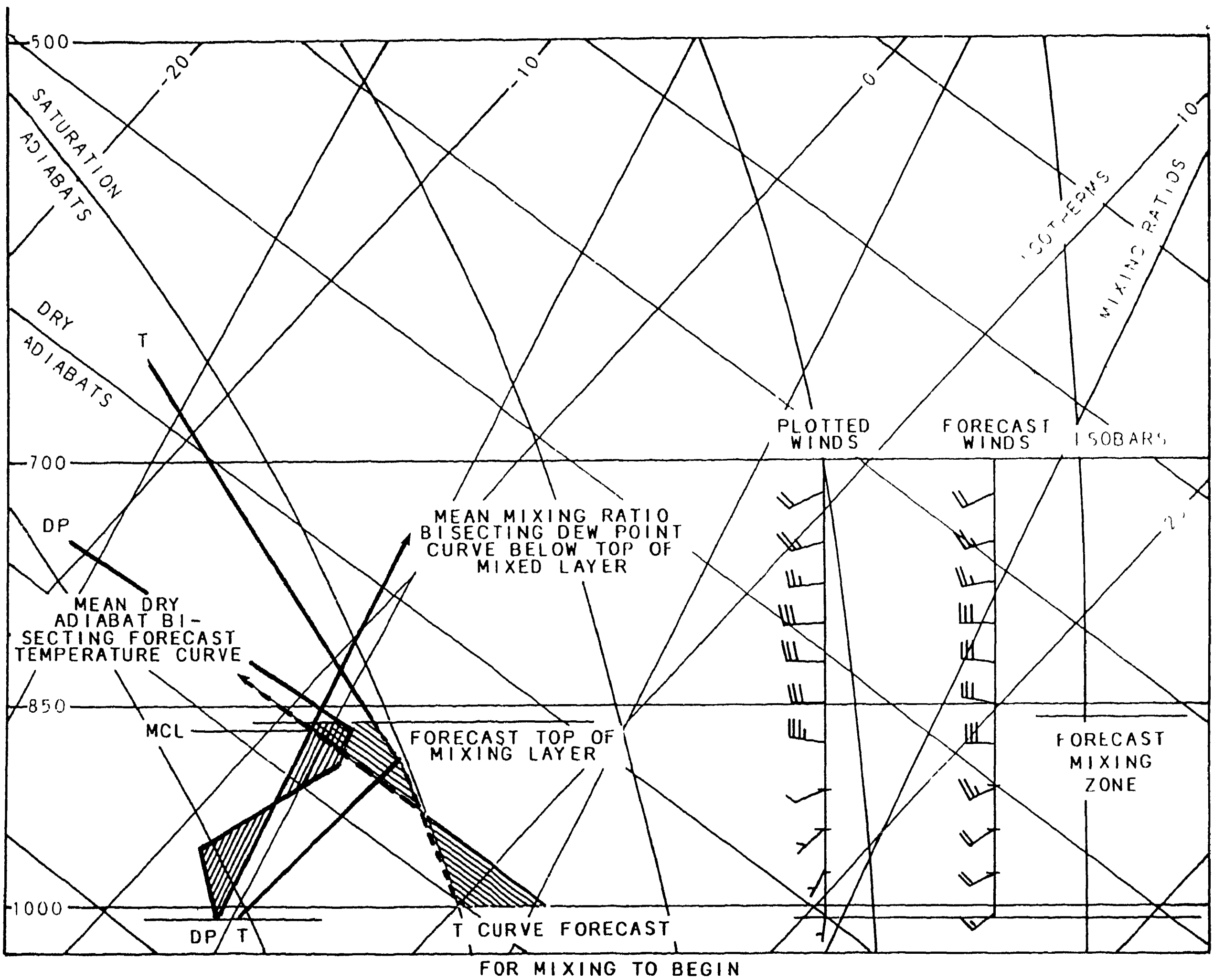

Figure 6-2-9.—Determination of the mixing condensation level.

mixing level. After the forecaster has made these changes on the Skew T, you can compute MCL as follows:

1. Draw a horizontal line at the level of the top of the mixed layer.
2. Bisect the dew point curve with a mixing ratio line by the equal area method.
3. Bisect the temperature curve with a dry adiabat by the equal area method.
4. MCL is the level at which the mean mixing ratio and the mean dry adiabat intersect. See figure 6-2-9 for an example of a computed MCL.

We have just looked at several methods used to determine where cloud bases will form. In reality, more than one factor can combine to start cloud formation. You may have a frontal surface moving through your area that will provide mechanical lift, but daily heating may occur to add convective lift to the process. You may have increasing winds to add mixing to the process. The forecaster must take these factors into consideration when applying the guides you have calculated to his forecast.

Just how high will these clouds develop after they form? Well, let's find out.

Level of Free Convection (LFC)

Level of Free Convection (LFC) is the level at which a parcel of saturated air becomes warmer than the surrounding air and rises freely. LFC in figure 6-2-10 is computed as follows:

1. Find LCL.
2. Draw a line upward from LCL parallel to the nearest saturation adiabat until your line intersects the plotted temperature curve. This is LFC.

Free convection in the atmosphere differs from forced convection in that free convection is brought about by one thing only—density differences within the atmosphere. When the required density difference does not exist, LFC

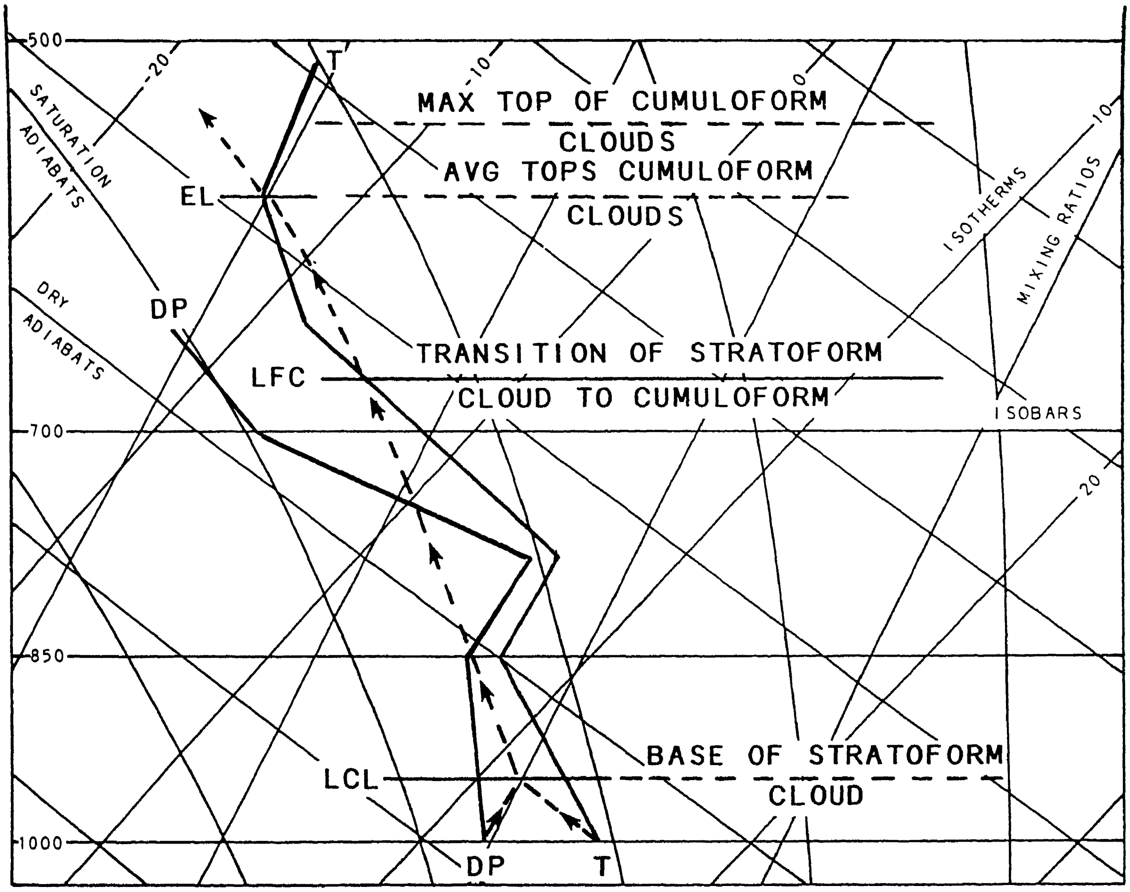

Figure 6-2-10.—Computation of the level of free convection.

will not exist. In such cases, the saturation adiabat drawn upward on the Skew T from LCL fails to intersect the plotted temperature curve.

Once a cloud in the developing stage reaches LFC, the cloud will continue to develop until it enters a level where the surrounding air is cooler than the air in the cloud top. We will look at this in more detail in the following section on positive energy areas and negative energy areas.

Positive Energy Areas and Negative Energy Areas

Within the atmosphere, there are areas of positive energy and negative energy that control stability. These areas may be convectively or mechanically induced. The type and size of these energy areas often determine the type of weather that will occur over a region. When a parcel of air lies in a stable layer within the atmosphere, energy has to be supplied to it if the air parcel is to move up or down. Such a layer is classified as a negative energy area (NEA).

When an air parcel lies in an unstable layer within the atmosphere, energy need NOT be supplied to get the parcel to move. The parcel moves upward freely because it cools adiabatically and remains warmer than the surrounding air. Such a layer is known as a positive energy area (PEA).

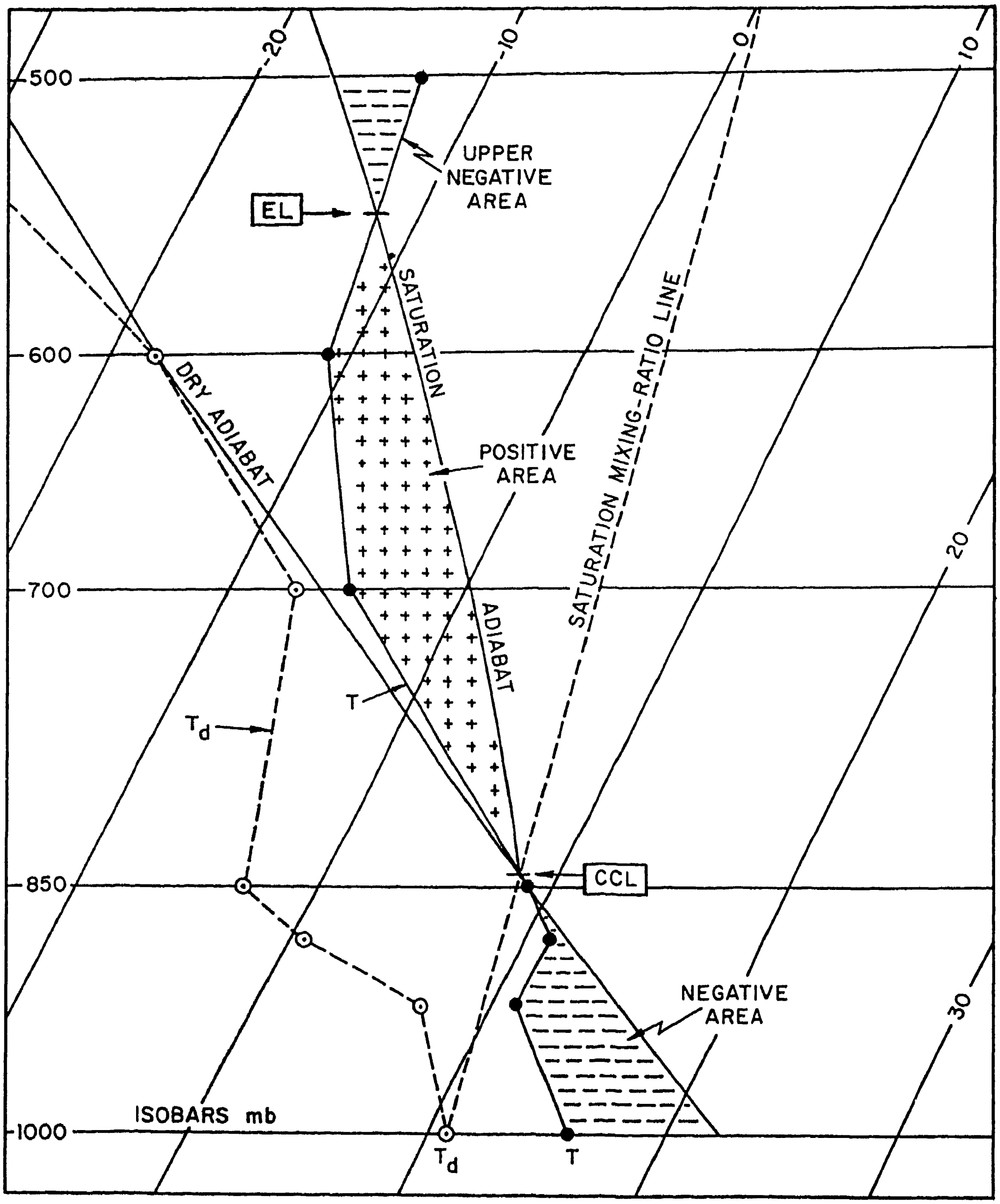

Figure 6-2-11.—Positive energy areas and negative energy areas (convective).

Refer to figure 6-2-11 to determine positive and negative energy areas pertaining to CONVECTIVE LIFTING. The procedure used in determining these areas is as follows:

1. Find CCL (moist-layer and/or parcel method).
2. From CCL, draw a line to the top of the chart paralleling the nearest saturation adiabat.
3. Draw a line from CCL to the surface paralleling the nearest dry adiabat.
4. Using a red pencil, shade in any area bounded by the temperature curve on the left and the drawn saturation adiabat on the right. These areas are the POSITIVE energy areas.
5. Using a blue pencil, shade in any area bounded by the temperature curve on the right and the drawn saturation adiabat on the left. These areas are the NEGATIVE energy areas.

Refer to figure 6-2-12 to determine positive energy areas and negative energy areas that pertain to MECHANICAL LIFTING. The procedure for determining these areas is as follows:

1. Determine LFC.

2. From LFC, extend the saturation adiabat to the top of the chart.

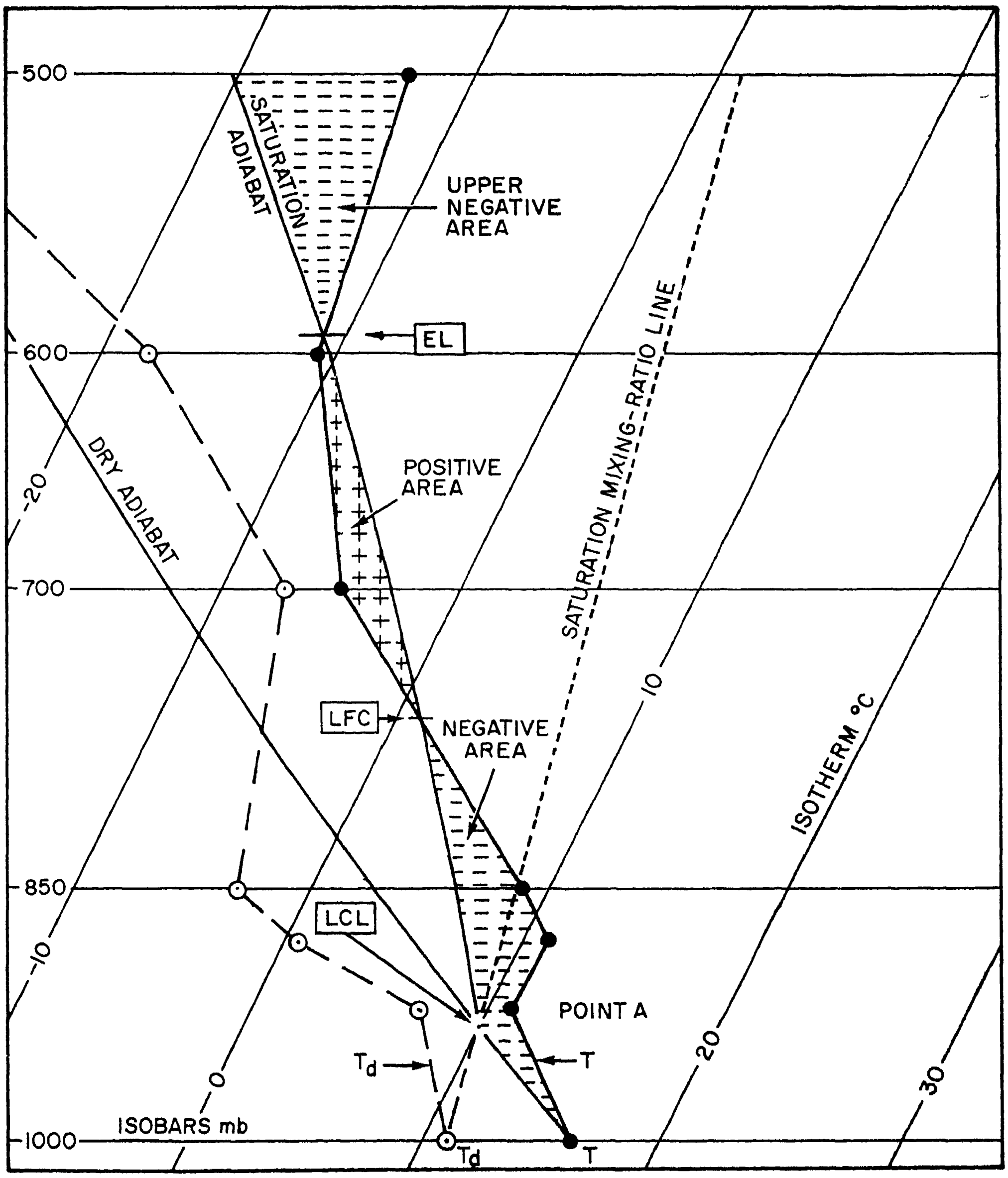

Figure 6-2-12.—Positive energy areas and negative energy areas (mechanical).

3. Using a red pencil, shade in any area above LFC that is bounded by the temperature curve on the left and the saturation adiabat on the right. These are PEAs.

4. Using a blue pencil, shade in any area above LFC that is bounded by the temperature curve on the right and the saturation adiabat on the left. These are NEAs.

5. Below LFC, shade in blue the area bounded on the right by the temperature curve, on the left by the dry adiabat, up to LCL, and by the saturation adiabat on the left from LCL to LFC.

Equilibrium Level

Equilibrium Level (EL) is the height where the temperature of a freely rising parcel of air again becomes equal to the surrounding air. It is found where the saturation adiabat drawn upward from CCL_P, CCL_{ML}, or LCL crosses the temperature curve from right to left. This is the level your energy area analysis changes from red to blue. You may find more than one EL on a certain sounding, just as you may find multiple PEAs and NEAs above LFC. Generally, you can equate EL to be the top of a stratiform cloud layer, but in the case of strong convective activity, overshooting tops of cumulonimbus clouds may extend through EL by one-third the depth of PEA. For example, if PEA extends from CCL_{ML} at 4,000 feet all the way to an EL at 32,000 feet, you may calculate the maximum convective cloud tops to be as high as 41,300 feet.

So far we have looked at methods of computing the levels different types of clouds will form. However, analyzing clouds on the Skew T includes more than calculating where clouds will form. We must also be able to determine what layers already exist and what types of clouds are in the layers. This information will help the forecaster to predict the sky cover accurately. In the next section we will see how to determine where cloud layers should already exist and what types of clouds should be there.

Learning Objective: Identify the criteria used in cloud layer analysis on the Skew T.

CLOUD LAYER CRITERIA

The Skew T gives you, the analyst, the best information to evaluate where cloud layers are and the type of cloud in each layer (short of sending an observer up in an aircraft). Analysis of moisture and winds can help you identify cloud layers missed by your observer at night or hidden by a low overcast. In this section we will see how to identify cloud layers by their moisture content and how you can identify the cloud type. We will also look at the association between cloud temperatures and precipitation, and some limitations in the identification of the taller cumuloform and cirriform clouds.

Cloud Layer Analysis

Studies have shown that water vapor becomes visible, as either minute water droplets or ice crystals, well below the saturation point. Other studies have correlated radiosonde observed temperatures and moisture measurements with aircraft observed cloud layers. While most aircraft reported cloud layers were supported by raob data, many thin or scattered cloud layers reported by aircraft often were not evident in the raobs. This was often interpreted as an accepted deficiency due to the lack of sensitivity of the older hygristors in the radiosondes. Nevertheless, the studies did find definite relationships between observed relative humidities and cloud layers. Figure 6-2-13 shows the relationship between the dew point depression and cloud coverage that was determined by the study. Note that these results relate the dew point depression to the probability of occurrence of a scattered or overcast cloud layer. This study and other similar studies provided the basis for the following rules, which are used to analyze cloud layers on a Skew T.

- A cloud base may be inferred to be located where the dew point depression decreases to 5 °C or less when the air temperature is above freezing, or where the frost point depression is 5 °C or less when the air temperature is below freezing. This is especially true if the dew point or frost point depression shows a sudden decrease near the same level.

- Dew point depressions in a cloud, on the average, are greater at cooler temperatures[1]. Use

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[1] A part of the difference is due to deficiencies in the hygristor circuitry of the radiosondes. This discrepancy may be reduced somewhat using the Vaisala® Mini Sonde. Manufacturer's data indicates that the Humicap® humidity element has a much greater sensitivity and less lag time than the hygristor of the widely used Viz® J005/J006 sondes and forerunners.

reports may give you a good idea of what the vorticity pattern may be over your area. Veering wind directions with height (direction changing clockwise with increasing height) usually indicate a positive vorticity pattern, while backing wind directions with height (directions changing counterclockwise with increasing height) usually indicate a negative vorticity pattern. As you probably remember, positive vorticity indicates lift and an upward transport of air, so you should expect cloud layers to increase in density. Negative vorticity, on the other hand, should gradually dissipate cloud layers.

Cloud Type Analysis

An evaluation of directional and speed shear in a moist layer also gives an indication of the type of cloud that may be present. Relatively little shear indicates a stratiform cloud layer, while larger shear should be associated with a strato-, alto-, or cirro-cumuloform layer.

A thumb rule for finding the type of cloud in a layer uses the thickness of the moist layer as an indicator. If the layer is 1,000 to 4,000 feet thick, the cloud is stratiform; 5,000 to 9,000 feet thick, the cloud is cumuloform; and over 10,000 feet thick, it is towering-cumuloform. This thumb rule should not take precedence over an analytical procedure. Obviously it does not do justice to nimbostratus cloud layers.

Identification of the cloud genera is more straightforward. By definition, clouds with bases below 6,500 feet AGL are low-etage clouds: 6,500 feet to 18,500 feet AGL are mid-etage clouds, and above 18,500 feet AGL are high-etage clouds. Consult your *AG3* manual for a further breakdown of the low, mid, and high cloud types.

ASSOCIATION OF CLOUD TOP TEMPERATURES AND PRECIPITATION.—The type and intensity of precipitation observed at the surface is related to the thickness of the cloud aloft and particularly to the temperatures in the upper part of the cloud. The processes that cause cloud particles to grow and precipitate out of clouds have received much attention during the past 30 years or so. However, our knowledge of the process is far from complete.

The results of one study relating cloud-top temperatures to precipitation type and intensity are applicable to the Skew T analysis when analyzing stratiform clouds. In 87 percent of the cases where drizzle was reported at the surface, the cloud-top temperatures were colder than −5 °C. The frequency of rain or snow increased markedly when cloud-top temperatures fell below −12 °C. During continuous rain or snow, cloud-top temperatures were below −12 °C in 95 percent of the cases. Intermittent rain or snow fell from clouds with cloud-top temperatures colder than −12 °C in 81 percent of the cases, and colder than −20 °C in 63 percent of the cases. From this we can derive the rule that drizzle should be expected only when cloud-top temperatures are colder than −5 °C and that continuous or intermittent rain or snow should be expected only when stratiform clouds, either layered or continuous, have cloud-top temperatures colder than −12 °C. We <u>cannot</u> reverse this rule and say that we should expect precipitation if cloud-top temperatures are below −5 °C. Whether precipitation occurs or reaches the ground depends on (1) the amount of moisture present, (2) if there is some lifting mechanism to bring the moisture to saturation and continued lift to force precipitation of the excess moisture, (3) the cloud thickness, (4) the height of the cloud base above the ground, and (5) the dryness of the air below the cloud base.

LIMITATIONS OF THE DIAGNOSIS OF TOWERING CUMULUS AND CUMULONIMBUS CLOUDS ON A SKEW T.—The towering cumulus and cumulonimbus of summer- and tropical-air-mass situations are generally scattered. In many, if not most cases, they do not actually cover even half of the sky. Under such conditions, the probability that radiosondes released once or twice daily from fixed locations will pass up through a cloud of this type appears small. When a sonde does enter such a cloud, it is likely to pass out of the side rather than the top. Electrical charges in active thunderstorms have been seen to affect the sonde's circuitry, yielding erratic readings.

Soundings that do pass through these clouds will often show unrepresentative values. The temperature in some parts of these clouds is often

colder than that of the ambient, or surrounding, air. The lapse rate will not necessarily be saturation adiabatic, because of the effect of downdrafts, snow or hail melt, or entrainment and mixing. While humidity readings will be high, they also will not be representative of the surrounding air.

For these reasons, we cannot rely on a sounding to directly indicate the presence of tall cumulus clouds or the coverage by these clouds. Satellite, radar, or ground observations are our best indication of the presence and coverage of these clouds.

LIMITATIONS OF CIRRUS CLOUD IDENTIFICATION.—True cirrus clouds form at temperatures near −40 °C, or colder. Present rules for encoding Rawinsonde reports establish a cutoff point for reporting the dew point depression at this same temperature. This cutoff temperature was established because the hygristor elements in the older radiosondes were not reliable, and the data received from the sondes after that temperature was considered worthless. With the increasing use of the new humidity-measuring circuitry in radiosondes, this cutoff temperature may be changed to colder temperatures.

Although not routinely reported, data from upper-air soundings indicates cirrus clouds layers are observable by at least an increase in the moisture (decrease in dew point depression) at temperatures colder than −40 °C, even though the dew point was very low. If you are analyzing your own station's sounding, you should ignore the mandatory dew point cutoff for reporting and have the plotter enter the data on the Skew T. Analysis of this data using frost point calculations may yield some surprising heights for cirrus and may also end the typical standard observer entry for cirrus as either 20,000 or 25,000 feet.

Learning Objective: Define the use of and describe the computation procedures for commonly used stability indices on the Skew T.

STABILITY INDICES

A stability index is a computed value used to forecast the probability of convective activity. This activity may range from rain showers, through the various intensities of thunderstorms, ending up with thunderstorms producing tornadoes. Many different stability indices are currently being used as forecast aids for severe weather. We will look at the indices used most frequently that you as the analyst must be able to compute from the Skew T. These are the Showalter Stability Index, the Lifted Index, the K-Value or K Index, and the Total Totals Index.

Showalter Stability Index (SSI)

The *Showalter Stability Index* (SSI) is the stability index most used by the National Weather Service, the USAF Air Weather Service, and Navy forecasters. It indicates the general stability of an air mass and should not be used when a frontal boundary or a strong inversion is present between the 850- and 500-millibar levels. SSI is computed using the layer between 850 millibars and 500 millibars, as follows:

1. Using the temperature and dew point at the 850-millibar level, determine LCL.

2. From that LCL, draw a line upward parallel to the nearest saturation adiabat until it intersects the 500-millibar level. Read the temperature (T') at this point.

3. Subtract T' from the actual 500-millibar temperature (T_{500}). This value, including the algebraic sign, is the SSI value. See figure 6-2-14.

The probability of convective activity based on the SSI is as follows:

SSI VALUE	INDICATED WEATHER
>+3	RW/SW unlikely
+3 to +1	RW/SW probable and a slight chance of weak TSTM
+1 to −3	Increasing chance of TSTMS
−3 to −6	Probable Severe TSTMS
<−6	Possible TORNADOES

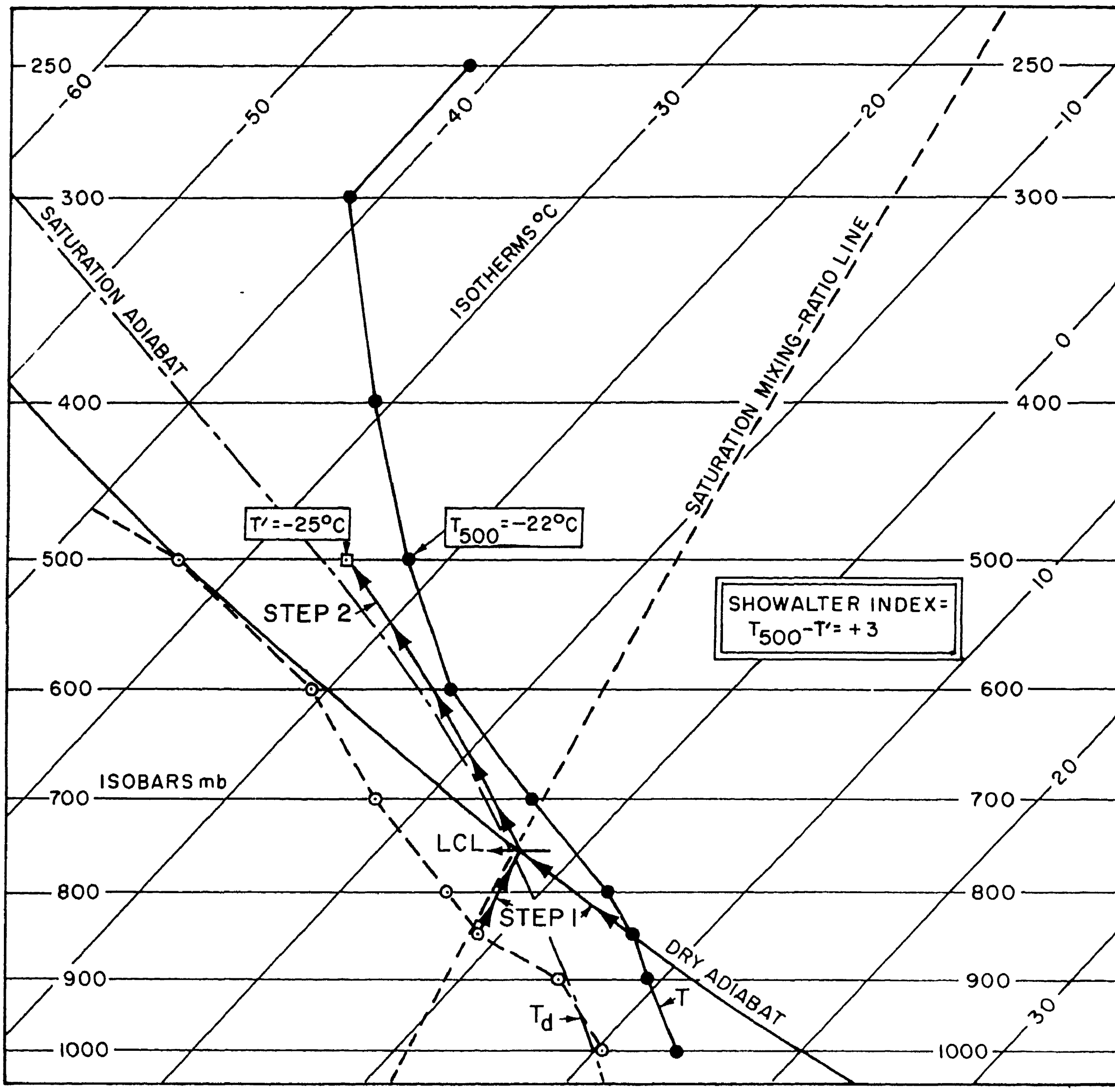


Figure 6-2-14.—Example of the Showalter Stability Index computation.

Lifted Index

Lifted Index (LI) is a modification of the Showalter Stability Index that is applicable for both air mass and frontal convective weather. The Lifted Index and the K-value (which we discuss in the following section) are routinely computed by the National Weather Service computers for all NWS U.S. Upper Reporting Stations and plotted on a chart for broadcast twice daily with the analysis package. The Lifted Index is computed from a Skew T as follows:

1. Determine the mean mixing ratio in the lowest 3,000 feet of your sounding by the equal area method.

2. Draw the expected maximum temperature adiabat:

a. If the 850-millibar level is $\geq$3,000 feet from the surface:

(1) if there are thick clouds on the current sounding, extend a saturation adiabat through the 850-millibar temperature so that it intersects your mean mixing ratio line; or

(2) if clouds are not expected to develop until afternoon, extend a dry adiabat through the 850-millibar temperature until it intersects the mean mixing ratio line.

b. If the 850-millibar level is within 3,000 feet of the surface, use the 3,000-foot temperature instead of the 850-millibar temperature to construct a dry or saturation adiabat.

3. The intersection of the mean mixing ratio and the adiabat is the Lifted Index LCL. Extend a saturation adiabat upwards from this LCL to the 500-millibar level. This 500-millibar temperature is assumed to be the updraft temperature within a convective cloud, should one develop. Subtract this temperature from your actual 500-millibar temperature to obtain the LI value. An example is shown in figure 6-2-15.

The value of LI is approximately the same as that of SSI.

K Index

K Value or *K Index* is a measure of thunderstorm potential based on the temperature lapse rate, the moisture content of the lower atmosphere, and the vertical extent of the moist layer. It should be used to analyze the potential for air mass thunderstorm occurrence—not potential occurrence of frontal thunderstorms and not for the potential severity of a thunderstorm. The temperature difference between the 850- and 500-millibar levels is the parameter used to find the vertical lapse rate, and the 850-millibar dew point and the 700-millibar dew point depression are used to evaluate the moisture content of the air, as well as the vertical extent of the moist layer. The K value is found as follows:

$$K = (T_{850} - T_{500}) + T_{d_{850}} - Dpd_{700}$$

where K = K value

T_{850} = 850-millibar temperature,

T_{500} = 500-millibar temperature,

$T_{d_{850}}$ = 850-millibar dew point temperature, and

Dpd_{700} = 700-millibar dew point depression

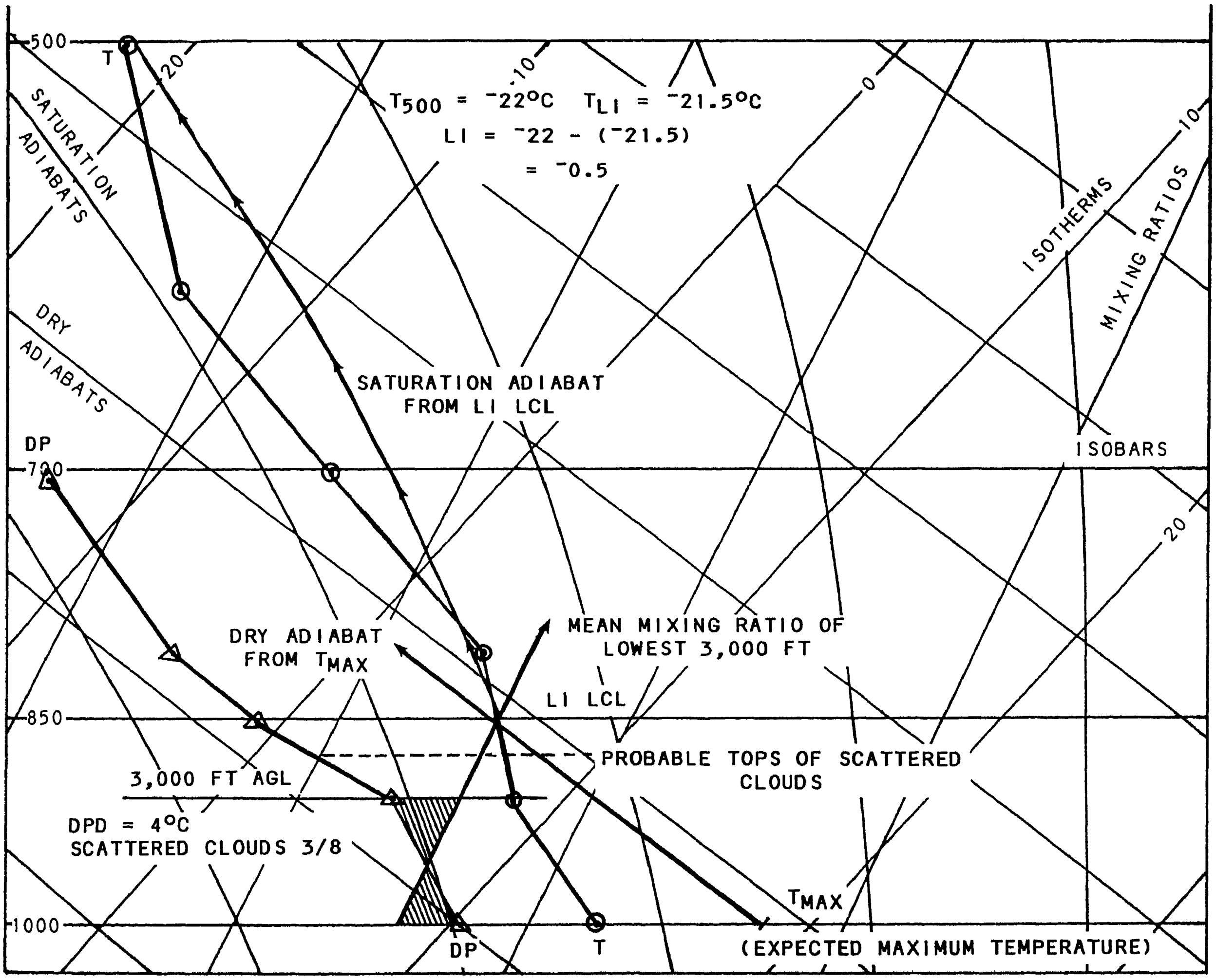


Figure 6-2-15.—Computation of the Lifted Index.

Using the K Value as a predictor, you can determine the probability of thunderstorms with the following guideline:

K Value	Thunderstorm probability, percent
<15	0
15-20	0-20
21-25	20-40
26-30	40-60
31-35	60-80
36-40	80-90
>40	near 100

Total Totals Index

Total Totals Index is actually a compound index designed to more accurately predict the occurrence of severe weather. It is used for both air mass and frontal thunderstorm activity and should be calculated whenever SSI or LI indicate that thunderstorms may occur. To calculate the Total Totals index, you must first algebraically compute two values: the *vertical total* (VT) and the *cross total* (CT). Each of these values is used along with the Total Totals to assess the probability of severe thunderstorm occurrence.

VT is a measure of vertical stability without regard for moisture. It is found by subtracting the 500-millibar temperature from the 850-millibar temperature.

CT is a measure of stability that includes moisture. It is found by subtracting the 500-millibar temperature from the 850-millibar dew point temperature.

The Total Totals (TT) index is simply the sum of VT and CT.

The forecaster will evaluate thunderstorm potential according to the general guidelines presented in table 6-2-1. While it is advisable to consider the VT and CT values, in common practice the TT index is the more reliable single predictor of severe activity in both warm- and cold-air situations. During 1964 and 1965, 92 percent of all reported tornadoes occurred with a TT of 50 or greater, with most family-type tornadic outbreaks occurring with a TT of 55 or greater. However, TT must be used with careful attention to either the CT value or the actual low-level moisture, since it is possible to have a large TT value with insufficient low-level moisture to support thunderstorms.

There are numerous other severe weather indices in use. Many of these are used at the National Severe Storms Forecast Center, by forecasters who specialize in severe weather forecasting. The indices presented here are those you should routinely evaluate when analyzing a Skew T diagram. If your calculated indices lead to a forecast of thunderstorm activity, your forecaster may ask you to calculate some additional parameters for wind gusts, convective turbulence, hail occurrence, and hail size. The procedures used to find these guides are presented in the next section.

Learning Objective: Describe the computation procedure for convective activity forecast guides on the Skew T, Log P Diagram.

COMPUTATION OF CONVECTIVE ACTIVITY FORECAST GUIDES

As the analyst of the Skew T diagram, you will calculate critical values upon which the forecaster will base his thunderstorm forecast. You have already determined that thunderstorms may occur and have used the indices to find a probability of occurrence and a prediction of the general strength of the expected thunderstorms. Now the forecaster must make a determination of the maximum gusts expected and what size hail is expected, if any. With this information, the forecaster may issue a thunderstorm warning or recommend that the proper thunderstorm condition be set. The following techniques will allow you to calculate wind gust speed and direction, to determine if hail is expected, hail size, and the strength of turbulence expected in the convective activity.

Table 6-2-1.—Relationship of Severe Weather Intensities to the Magnitude of Cross-, Vertical-, and Total-Totals Indexes

FORECAST	CT	VT	TT
ISOLATED to FEW Orange	18-19	≥26	44
SCATTERED Orange FEW Green	20-21	≥26	46
SCATTERED Orange FEW Green ISOLATED Blue	22-23	≥26	48
SCATTERED Green FEW Blue ISOLATED Red	24-25	≥26	50
SCATTERED to NUMEROUS Green FEW to SCATTERED Blue FEW Red	26-29	≥26	52
NUMEROUS Green SCATTERED Blue and Red	≥30	≥26	≥56

Red = Severe Thunderstorms w/tornadoes a/o waterspouts
Blue = Severe Thunderstorms (max gusts ≥50 kts, a/o hail >1″)
Green = Moderate Thunderstorms (max gusts ≥35 kts but <50 kts, a/o hail ≥1/2″ but ≤1″)
Orange = Thunderstorms (max gusts <35 kts a/o hail <1/2″)

REGIONAL MODIFICATIONS:

WEST OF THE ROCKIES - 700 and 500 millibar dew point depressions should be less than 6 °C to insure sufficient low level moisture or 500 millibar temperature should be ≥−17 °C and 700 millibar temperature should be ≥0 °C. If this is satisfied, then consider: (a) VT <28 = No thunderstorms. (b) VT ≥28 but ≤32 = Few thunderstorms. (c) VT ≥32 = Scattered thunderstorms. Usually these will be Orange variety. Green or blue require large amounts of moisture at 850 and 700 millibars.

PACIFIC COASTAL MOUNTAINS, WINDWARD SLOPES - Vertical totals are most important predictor, especially when associated with PVA and cyclonic flow aloft. Over OR, WA and northern CA VT ≥30 will usually produce Cumulonimbus with few Tstms and hail pellets.

EAST OF ROCKIES - Use above values if sufficient low level moisture is present.

GULF COAST AND GULF STREAM - Predict thunderstorms if CT ≥16 and VT ≥23.

GREAT LAKES - Vertical totals are the more important predictor. Any value ≥30 should produce thunderstorms, except if the lakes are frozen over or mostly frozen over.

Calculations for Convective Wind Gusts

There are two methods for calculating convective gusts. These are the T_1 and T_2 methods. The T_1 method is used to predict average maximum gusts and the maximum wind gust in air mass thunderstorms. The T_2 method should be used to compute the maximum wind gust in frontal thunderstorms or in a prefrontal squall line, when numerous air mass thunderstorms are expected, or when an air mass meso-scale convective thunderstorm complex threatens your station. In brief, use the T_1 method for thunderstorm gusts at your station when thunderstorms are expected in the vicinity, and use the T_2 method if a thunderstorm is expected to pass directly over your station with heavy rain. The maximum downrush wind or microburst will occur as the transition between the mature stage and the dissipating stage of a strong thunderstorm coincident with the beginning of the heaviest precipitation.

The most severe weather appears to occur in areas where the height of the Wet-Bulb-Zero (WBZ) is less than 10,500 feet. Wet-Bulb-Zero heights between 7,000 and 9,000 feet above the ground are most closely associated with destructive surface winds caused by microbursts from thunderstorms. Microbursts are extremely rare with a WBZ height lower than 5,000 feet or higher than 10,500 feet. It seems the WBZ height is a reliable preliminary indicator of microbursts and the associated strong wind gusts from thunderstorms.

If the WBZ height on your Skew T falls between 5,000 and 11,000 feet, then the analysis should be continued with either the T_1 method or the T_2 method, as applicable.

$\underline{T}_1$ Method For Air Mass Convective Gusts

The T_1 method uses the calculated difference between the temperature of a parcel of moist surface air raised moist adiabatically to 600 millibars and the 600-millibar temperature as a guide to determine the surface wind gusts. The computation procedure is as follows:

1. Have the forecaster determine what time the thunderstorms are expected to occur, and the maximum temperature expected during that time period.
2. If an inversion is present within 200 millibars of the surface and the inversion will not be removed by diurnal changes, from the warmest point in the inversion ascend moist adiabatically to 600 millibars, and record the temperature. If no strong inversion is present, ascend moist adiabatically from the predicted maximum temperature to 600 millibars, and record this temperature.
3. Subtract the actual 600-millibar temperature from the temperature you just found and recorded. The difference between these two temperatures is the T_1 temperature.
4. Enter table 6-2-2 with T_1 to find the average maximum gust speed (V'). The table is

Table 6-2-2.—Average Maximum Convective Wind Gusts for the $\underline{T}_1$ Method

T_1 Values in °C	Maximum Gust Speed (V')	T_1 Values in °C	Maximum Gust Speed (V')
3	17	15	49
4	20	16	51
5	23	17	53
6	26	18	55
7	29	19	57
8	32	20	58
9	35	21	60
10	37	22	61
11	39	23	63
12	41	24	64
13	45	25	65
14	47		

based on the formula $V' = 13\sqrt{T_1}$ with some empirical adjustments.

5. Calculate the mean wind speed in the surface-to-5,000-foot layer.

6. Add one-third of the mean surface-to-5,000-foot wind to V' to find your maximum probable gust speed. This is the T_1 predicted gust speed.

T_2 Method for Computing Maximum Convective Gusts From Frontal or Air Mass Thunderstorms

The T_2 method uses the difference between the WBZ potential temperature and the predicted maximum surface temperature at the time thunderstorms are expected as a predictor of the probable maximum gust speed to expect from a thunderstorm outbreak. The gust speed is found by the following steps:

1. Have the forecaster determine what time thunderstorm activity will commence and what the maximum temperature will be at that time.
2. Locate the WBZ.
3. Descend moist adiabatically from WBZ to the surface and record this temperature.
4. Subtract this temperature from the predicted maximum temperature at the onset of the thunderstorm activity to find T_2.
5. Enter figure 6-2-16 to find the probable range of the expected maximum gust speed. This figure does not yield average gust speeds or

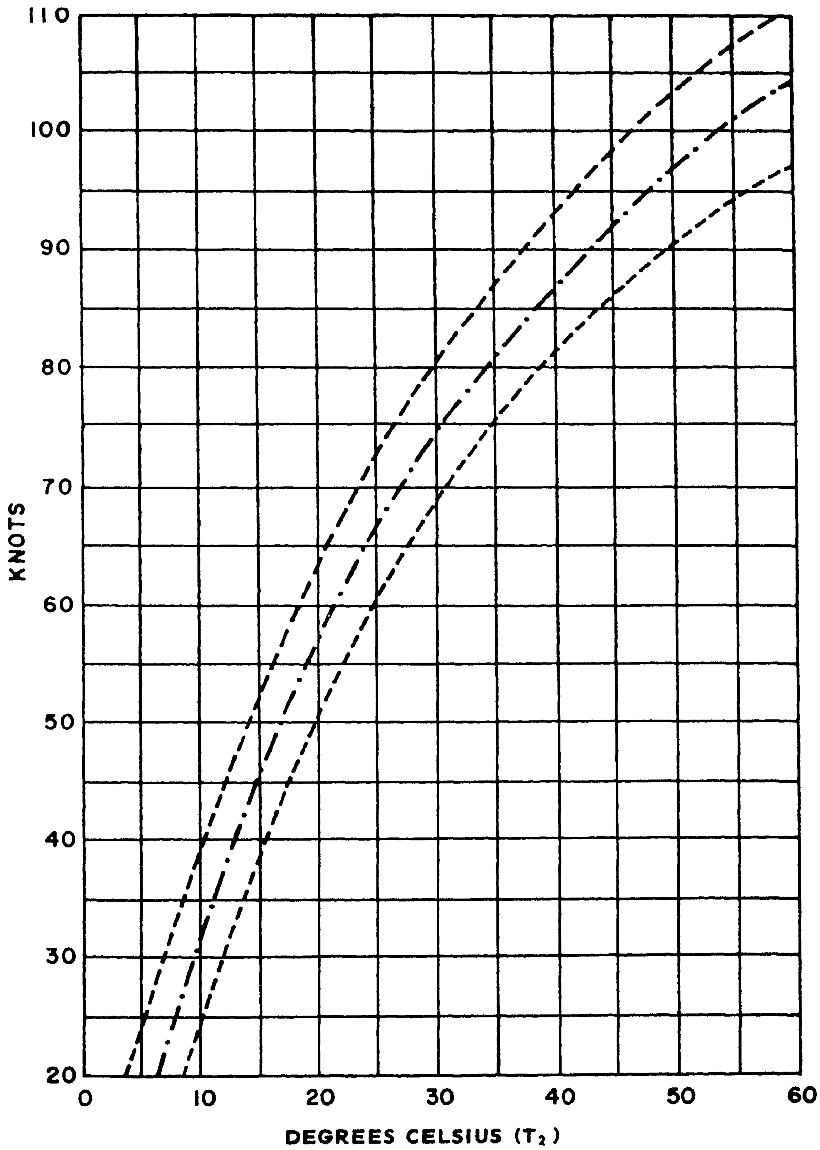


Figure 6-2-16.—T_2 method maximum convective wind gust speed diagram.

minimum gust speeds. If T_2 is 20 °C, for example, you would tell the forecaster that the expected maximum gust will be in the 51- to 68-knot range, with a most probable value of 57 knots. You may wish to think of the three lines as "best case," "most probable case," and "worst case."

Computation of Gust Direction

Once you have calculated the gust speed, use the plotted wind speeds and height scale to find the mean wind direction in the 10,000 foot to 14,000 foot AGL layer. Use this direction as the direction for the maximum gust. Remember, a thunderstorm downrush, with its associated gusts, spreads out in all directions under the thunderstorm base. Your maximum gust direction should generally be in the same direction the storm is moving. When calculating a maximum gust direction in a frontal thunderstorm, you should consider the 10,000- to 14,000-foot wind as representative even if the thunderstorm is occurring on the cool side of the surface position of the front. The slope of both warm and cold fronts allows either a warm sector sounding or a pre-warm frontal sounding to be representative for the 10,000- to 14,000-foot winds.

Calculating Convective Turbulence

The following is the modified Eastern Airlines method of calculating expected turbulence within

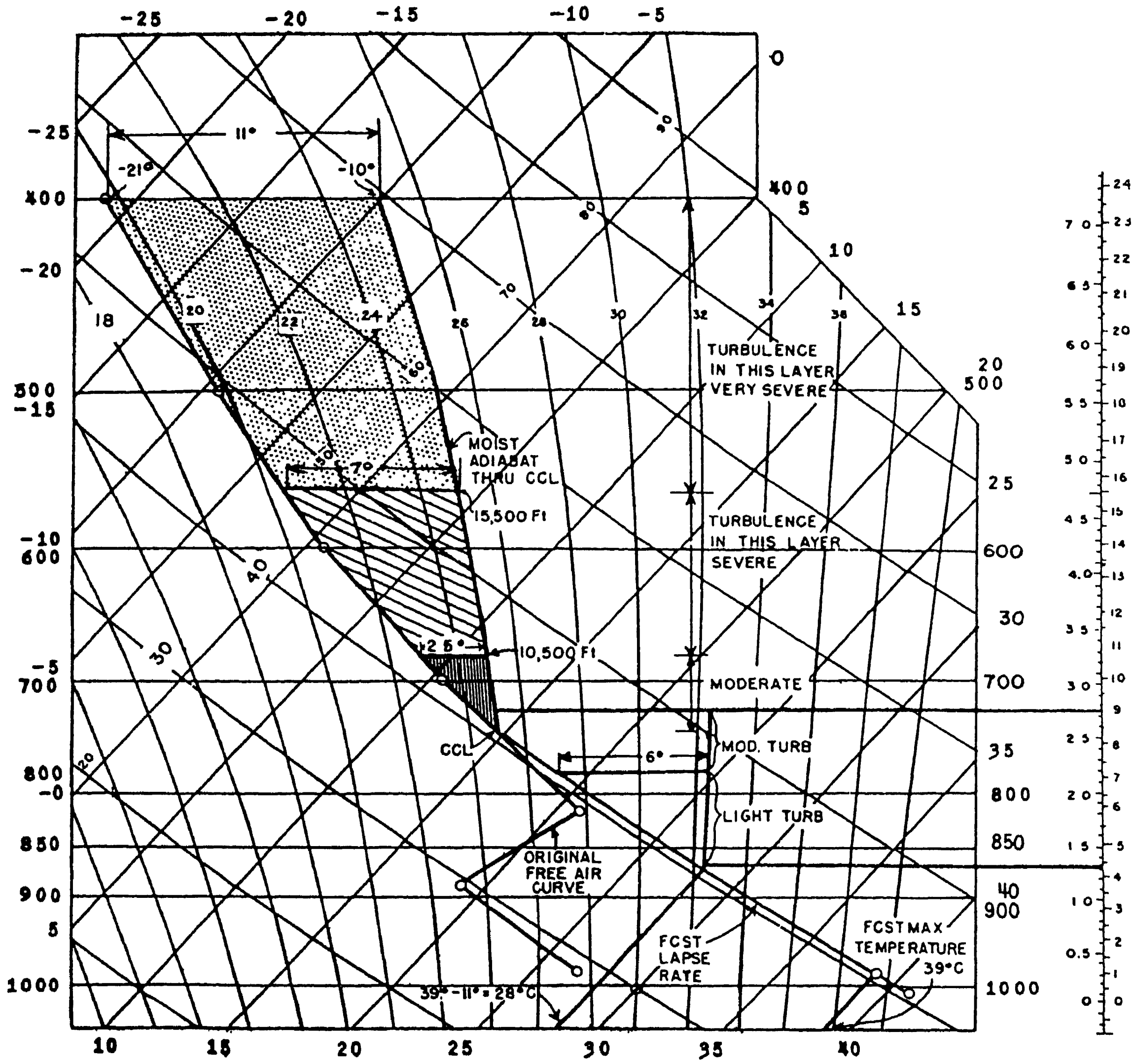


Figure 6-2-17.—Computation of convective turbulence.

a convective cloud, using a plotted Skew T, Log P Diagram. The resulting turbulence criteria are based on a medium-size, twin-engine, fixed-wing aircraft (DC-3/C-117/C-47, length 65 feet, wing span 95 feet) and must be adjusted subjectively for other aircraft. You may wish to follow along on figure 6-2-17 as you read through the computation procedure.

1. Divide the plotted atmosphere into two layers at the 9,000-foot MSL height.

2. Plot the forecast maximum temperature (FMT) on the surface level.

3. From the convective condensation level (CCL), descend dry adiabatically to the surface to locate the convective temperature (CT), and have the forecaster adjust CT according to local-objective techniques and expected insolation.

4. Subtract 11 °C from FMT to give a new temperature, which we will designate T_3.

5. Find the intersection of the T_3 isotherm and the dry adiabat projected upward from FMT.

- If the intersection occurs above 9,000 feet, no turbulence is expected below 9,000 feet. Go to step 7.

- If the intersection occurs below 9,000 feet, continue with step 6.

6. Draw a moist adiabat from the intersection upward to the 9,000-foot level. The temperature difference between this moist adiabat and the ambient temperature determines the severity of the turbulence that should be expected within convective clouds. Use the following guideline:

SURFACE TO 9,000 FOOT MSL LAYER	
TEMPERATURE DIFFERENCE, °C	TURBULENCE
0 to 5.9	LIGHT
6.0 to 10.9	MODERATE
$\geq$11	SEVERE

7. For the layer above 9,000 feet, project a moist adiabat upward from the CCL to the 400-millibar level. The maximum temperature difference between the moist adiabat and the free air temperature is the most turbulent layer. Turbulence will be classified as follows:

9,000 FOOT MSL TO ABOVE THE 400 MB LAYER	
TEMPERATURE DIFFERENCE, °C	TURBULENCE
0 to 2.4	MODERATE
2.5 to 6.9	SEVERE
$\geq$7	EXTREME

8. If two criteria overlap near the 9,000-foot level, use the greater turbulence.

9. If the CCL is above 9,000 feet, evaluate turbulence from CCL upwards only.

Computing Hail Occurrence

Just as the WBZ height is an important and reliable indicator of thunderstorm gusts, it is also a reliable preliminary indicator of hail occurrence. Research has shown that 84 percent of all cases of hail occur with the WBZ between 5,000 and 10,500 feet AGL. Furthermore, nearly all analyzed cases of hail larger than 1/2 inch occurred where the WBZ was near 8,000 feet AGL. Although many strong thunderstorms were studied where the WBZ was higher or lower than these values, most did not produce hail or strong gusts at the surface even though various indicators showed that the potential was present and that hail was almost certainly produced aloft. In the 16 percent of the cases where hail did occur at the surface with WBZ heights outside the 5,000- to 10,500-foot range, the hail fell only for a short period and was small. These cases occurred mostly in the states along the Gulf Coast.

Hail, like the maximum wind gusts, usually occurs in a narrow shaft seldom longer than a mile or two and less than a mile wide.

HAIL ALOFT.—Since hail is normally associated with thunderstorms, the season for hail occurrence is the season for thunderstorm

occurrence. When a thunderstorm is large and well developed, you should assume that it contains hail aloft. Below 10,000 feet, aircraft may encounter hail in the rain shaft under the storm, in the clear air within 2 miles of the storm cloud, and in the thunderstorm cloud itself, with equal probability. From 10,000 to 20,000 feet, 40 percent of aircraft hail encounters occur in the clear air under the overhanging tilted cumulonimbus column or the anvil, while 60 percent occur within the cumulonimbus column. Above 20,000 feet, 80 percent of hail encounters are within the cloud, while 20 percent are under the anvil. No computations are required to determine if hail is present aloft. Assume that it is.

HAIL AT THE SURFACE.—Will the hail reach the surface? If the WBZ height is favorable (5,000 to 11,000 feet for most areas), proceed with the following objective computation for a simple "yes" or "no" determination. If you are stationed along the Gulf Coast or in areas climatically similar to the Gulf Coast, you should use the procedure even though the WBZ exceeds 11,000 feet.

1. Find CCL_{ML}, EL, and the freezing level (FzL), in millibars.
2. Calculate the ratio of the depth, in millibars, of the freezing level to *CCL*, compared to the *EL* to *CCL* depth. This is the cloud depth ratio. It may be calculated as follows:

$$\text{ratio} = \frac{|\text{CCL} - \text{FzL}|}{\text{CCL} - \text{EL}}$$

3. Enter figure 6-2-18 with the cloud depth ratio and the freezing level, in millibars, for a "yes" or "no" prediction of hail reaching the surface.

Computation of Hail Size

This method of computing hail size is based on the estimates of updraft and downdraft velocities in thunderstorms and the resulting probabilities of hail produced in a thunderstorm

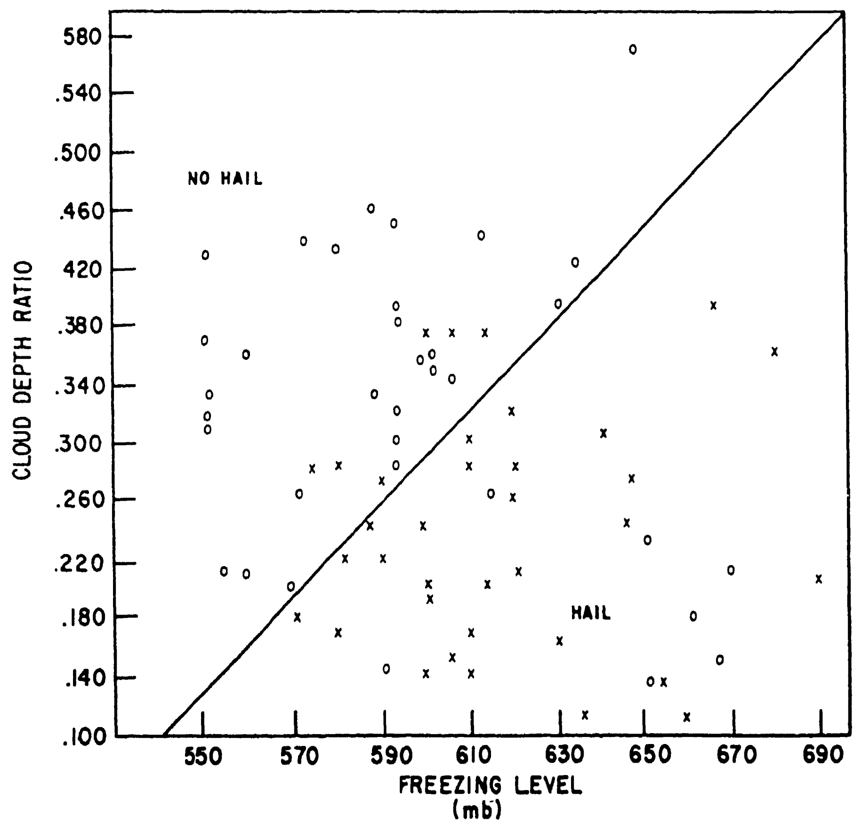
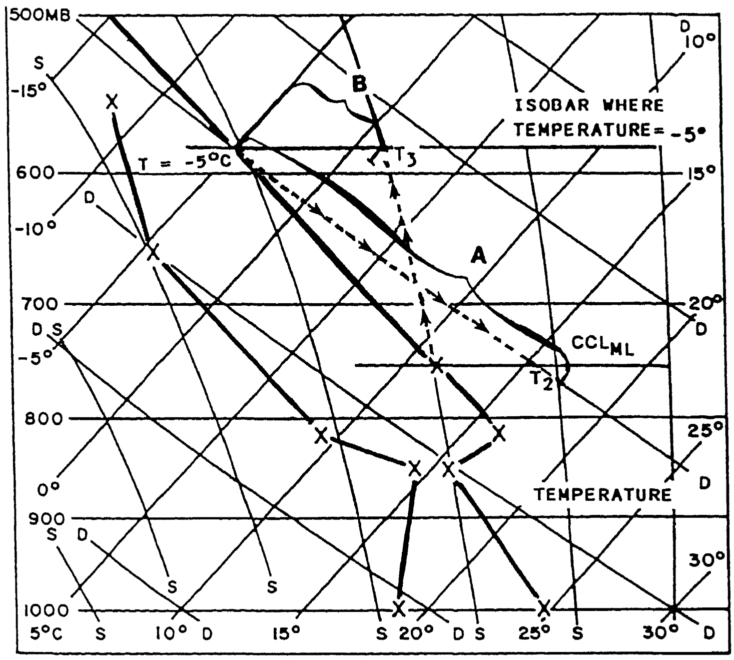


Figure 6-2-18.—Surface hail prediction diagram.

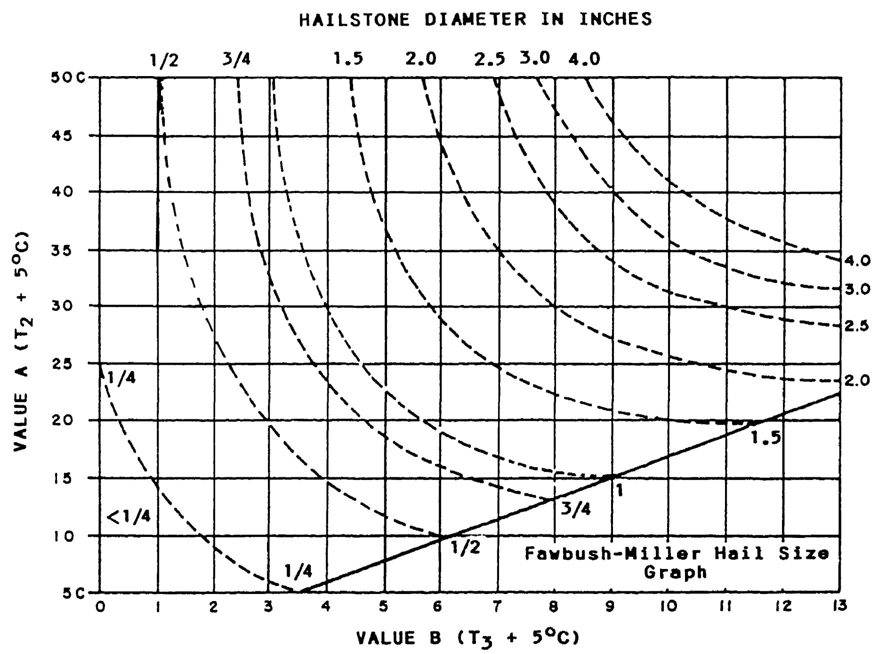
reaching the surface. This technique is called the Fawbush-Miller Hail Forecast method. The procedure to calculate hail size is as follows:

1. From the temperature curve at −5 °C, extend a dry adiabat downward until it intersects the pressure level of CCL_{ML}, and read the temperature at this intersection. We will call this temperature T_2 in our example, figure 6-2-19, view A.

2. Calculate the difference between this temperature (T_2) and −5 °C. Call this value A. The difference is $T_2 - (-5\ °C)$, or simply $T_2 + 5\ °C$.



(A)



(B)

Figure 6-2-19.—Surface-hail-size calculation: (A) Calculation example, (B) hail size graph.

3. From the CCL_{ML} intersection with the temperature curve, draw a saturation adiabat upward to intersect the pressure level where the air temperature is −5 °C, and read the temperature at this intersection. We will call this temperature T_3 in our example.

4. Calculate the difference between this temperature (T_3) and −5 °C. Call this value *B*. This difference is $T_3 - (-5\,°C)$, or simply $T_3 + 5\,°C$.

5. Enter figure 6-2-19, view B, with values *A* and *B* to find the hail size on the Fawbush-Miller Hail Graph.

6. If your WBZ is above 10,500 feet, enter figure 6-2-20 with the hail size from step 5 and your WBZ height to determine a corrected hail size.

Learning Objective: Describe the computation procedure for contrail formation analysis on the Skew T.

CONTRAIL COMPUTATION ON THE SKEW T DIAGRAM

Condensation trails, abbreviated *contrails*, are elongated, tubular-shaped clouds composed of water droplets or ice crystals which form behind an aircraft when the wake becomes supersaturated with respect to water. There are two types of contrails: aerodynamic contrails and engine exhaust contrails.

Aerodynamic contrails form by the momentary reduction of air pressure in the airfoil vortex. If you have ever seen the Navy Blue Angles or the Air Force Thunderbirds during a low-level demonstration, then you have probably noticed these contrails trailing the wing tips, especially during high-speed turns. These contrails appear as the vortex creates a partial vacuum, lowering the air pressure sufficiently to bring it to saturation. They dissipate rapidly as the pressure in the vortex returns to normal behind the aircraft. We will not be concerned with this type of contrail.

The second type of contrail is the engine exhaust contrail, formed by exhaust water vapor, a by-product of the combustion process, bringing the air to saturation. These are the conspicuous contrails you probably have seen crossing the sky, especially during the winter. Proper analysis of the temperature, humidity, and pressure will allow you to determine the heights at which contrails will form.

Why are we concerned with contrail analysis and forecasting? Contrails can make an otherwise inconspicuous high flying aircraft very noticeable

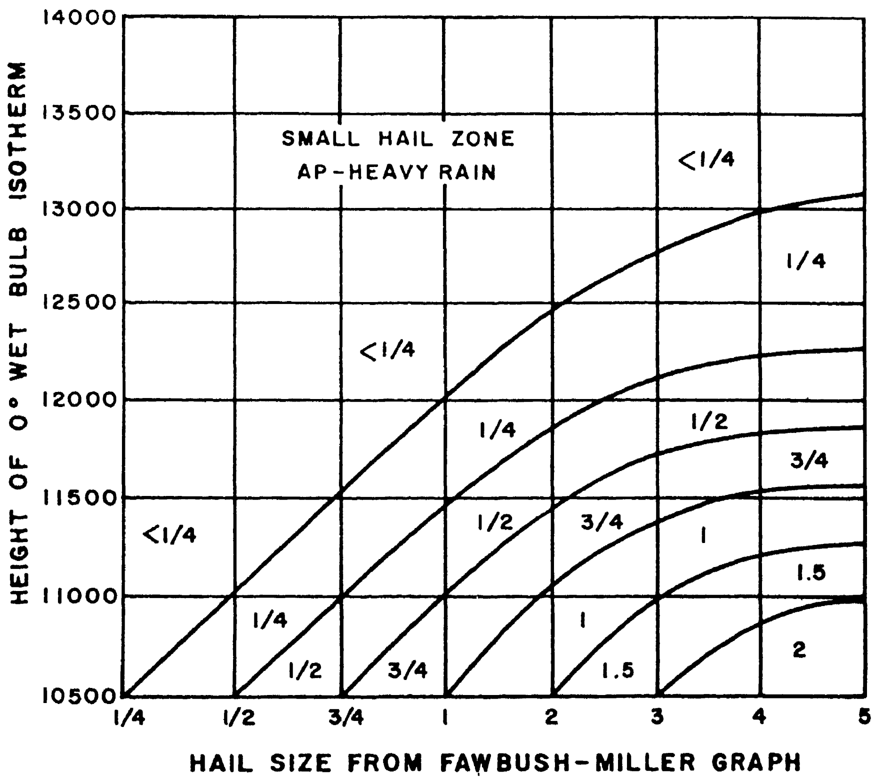


Figure 6-2-20.—Surface hail size correction diagram.

In a warfare situation or while conducting covert high-altitude photo-reconnaissance, a key to the success of the mission may be the element of surprise. Our aircraft may wish to avoid flight altitudes conducive to contrail formation to decrease the probability of their detection. Stealth technology aircraft will especially wish to avoid producing contrails. Shipboard, the CIC officer and the OOD can use your analysis of contrail formation altitudes to aid visual detection of high-flying hostile aircraft.

We have already identified the contrail scales and their values on the Skew T diagram earlier in this lesson. Given a specific level, you can use these scales, the temperature, and the humidity to determine if contrails will form.

When the free-air temperature is to the right of the 100 percent line, contrails will not form, regardless of the humidity.

When the free-air temperature is to the left of the 0 percent line, contrails will form, regardless of the humidity.

When the temperature is between the 0 percent and 100 percent lines, contrail formation depends on the humidity. The relative humidity must be equal to or greater than the value indicated by the line for contrail formation to occur. If the temperature at 300 millibars is −45 °C, for instance, the temperature is just to the right of the 60 percent line. I would call it about 67 percent. Contrails will form only if the relative humidity at that level (evaluated with respect to ice) equaled or exceeded 67 percent. Right about now you are probably thinking, "So how do I figure out the relative humidity when the moisture cut-off level is at −40 °C? There aren't any moisture reports at this level."

When the humidity data is unknown, empirical data indicates good results are achieved if 40 percent humidity is assumed where there are no clouds reported at the level, and 70 percent humidity is assumed when clouds are reported at a level. See figure 6-2-21 for an example of a contrail formation analysis where

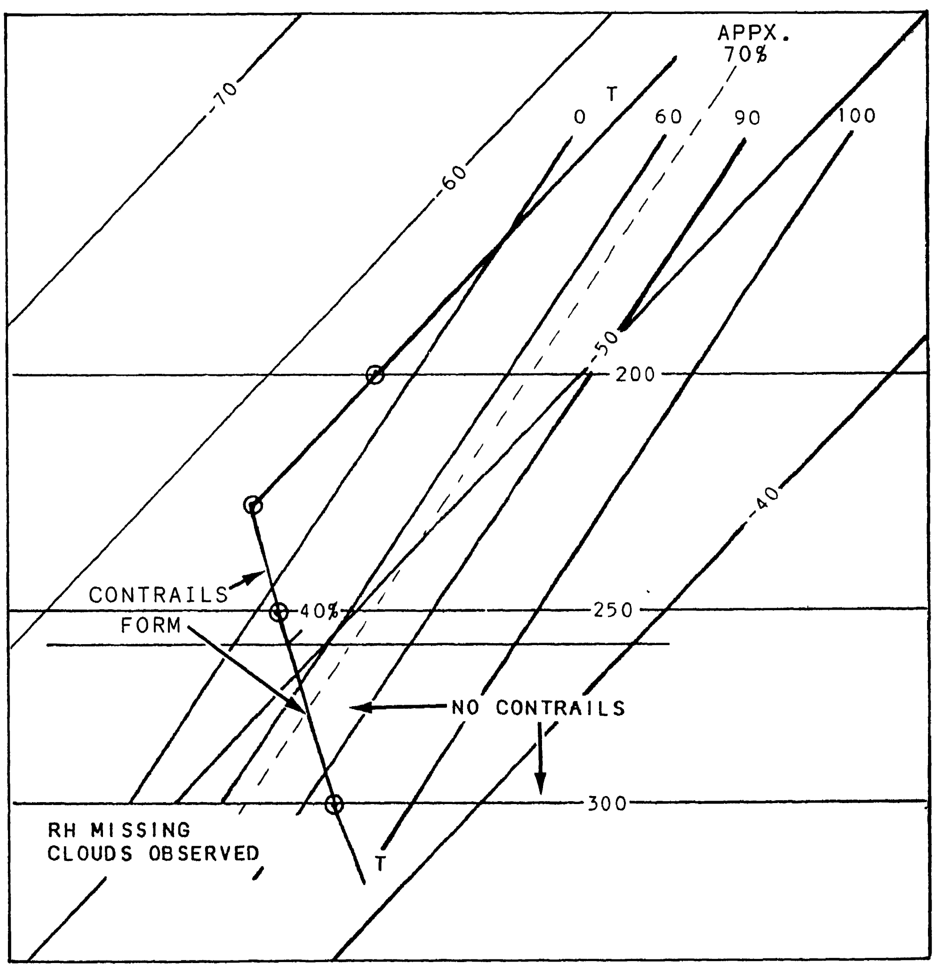


Figure 6-2-21.—Contrail computation.

clouds are present but relative humidity data is missing.

Learning Objective: Describe the computation procedures for icing level analysis on the Skew T.

ICING COMPUTATIONS ON THE SKEW T

You learned in the previous lesson how to evaluate icing type, and you were given some subjective rules for icing intensity. We must use more than "guesstimation" when flying safety is at stake. In this section we will discuss two icing analysis techniques for use on the Skew T. The Minus 8D technique is a method which gives a simple Yes or No evaluation of conditions favorable for icing. The second technique will yield a qualitative analysis of icing intensity. Although there are a lot of calculations that must be done in this technique, it is far better to use this technique than estimation when attempting to analyze and forecast hazardous conditions such as icing.

One of my most memorable days on the Flight Forecast Counter occurred one winter day, when analysis of data, including several Skew T's, indicated severe clear and mixed icing conditions north of NAS Norfolk, extending well north of Washington, D.C. I used the "Flight Not Recommended" stamp on three dash-one briefs to end the arguments by pilots who just "had to" fly to the D.C. area. Although two of the three pilots became very irate, I felt great about my decision after hearing of a tragic accident involving a major passenger jet that crashed into the Potomac River because of icing. They could have ended their flights the same way. If I had used estimation instead of qualitative techniques, I would not have been as sure about my forecast and may have let those determined pilots fly that day.

Minus 8D Icing Analysis

Physical observations of clouds often fail to give any indication of the composition of the clouds—whether they are water, water and ice mixed, or entirely made up of ice crystals. In any convective cloud, it is reasonable to assume that they are made of a mixture of ice and water at temperatures below freezing. In the stratus cloud, however, it is not safe to assume this. Clouds composed entirely of ice present little icing hazard. Clouds below freezing composed of mixed water and ice present a great icing hazard. Therefore, it is helpful if you know the cloud composition before you brief a flight through the cloud.

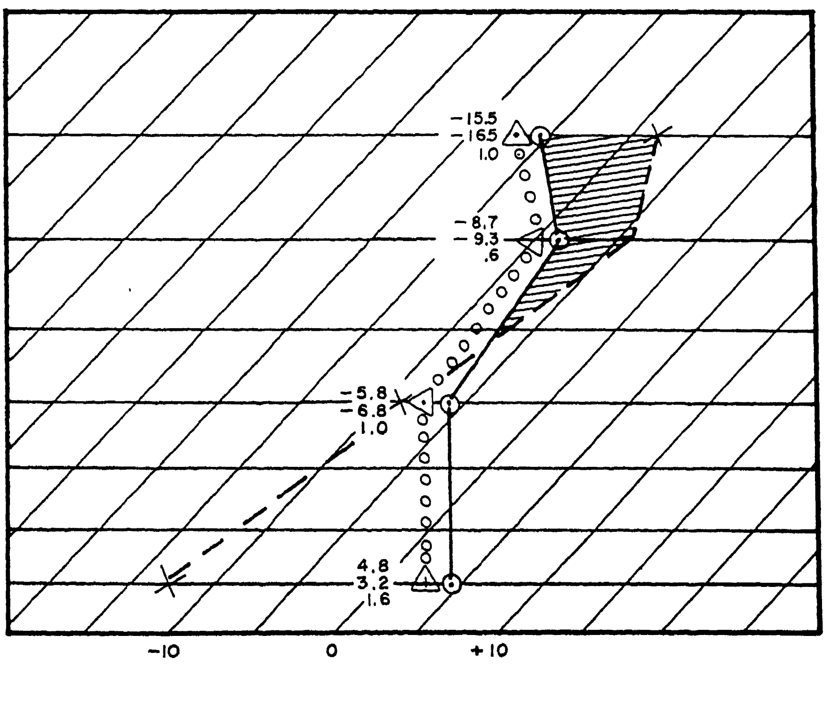


Figure 6-2-22.—Example of minus 8D icing analysis.

In a mixed ice and supercooled water cloud, evaluation of the dew point and the frost point would show that the cloud may be near or at saturation with respect to water but that the cloud would be supersaturated with respect to ice. We can assume that a cloud that is saturated with respect to ice would be subsaturated with respect to water and that it would consist entirely of ice crystals. Now, we could evaluate the humidity at all levels based on the dew point and frost point to see where icing will occur; or, we can use the *Minus 8D Icing Analysis* to show at a glance those areas that are supersaturated with respect to ice (are composed of supercooled water) and are therefore, icing areas. The procedure I find easiest follows:

1. Task the Skew T plotter to enter the reported dew point depression (as the chart is being plotted) just to the left of the dew point temperature plot for all levels where the air temperature is below freezing. An alternative is to calculate the difference between the plotted dew point temperature and the air temperature and enter this value (always a positive number) just to the left of the plotted dew point temperature. In this case, the value is called *D* even though it is the dew point depression. It should be found to the nearest tenth.

2. Multiply *D* by −8 and plot this value (°C) at the appropriate temperature on the same pressure level. For instance, if your dew point depression, or *D*, is 1.1, you would multiply this by −8 to find a product of −8.8 °C. This would be plotted on the appropriate isotherm. The color used for the plot is established locally. I have seen green used most often.

3. Connect all of your plotted −8D values with a line.

4. Conditions are favorable for aircraft icing where the line falls on the right side of the temperature curve. Evaluate flight levels for the base of each icing layer and the thickness of each layer, in thousands of feet, using the plotted pressure altitude curve. Pass this information to the forecaster.

See figure 6-2-22 for an example of a −8D analysis of an icing layer. This technique does not indicate the intensity or type of icing in a layer, only that icing conditions are favorable or unfavorable.

Maximum Icing Intensity Analysis

The two graphs in figure 6-2-23 may be used to evaluate the maximum probable icing in a cloud after you have determined that icing conditions

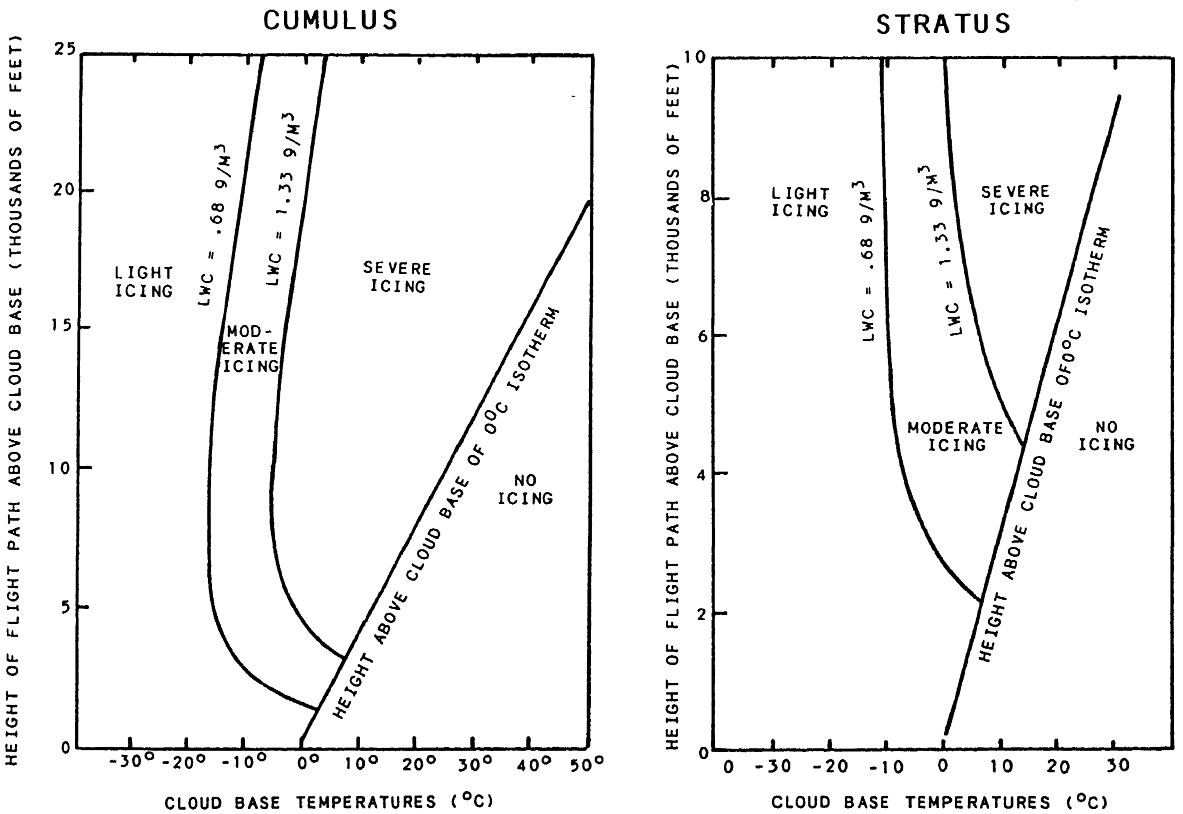


Figure 6-2-23.—Maximum icing probability graphs.

are favorable. These graphs were constructed from the formula:

$$LWC = (W_0 - W_1)\frac{P_1}{2.87T_1}$$

where LWC = liquid water content, in grams per cubic meter;

W_0 = saturation mixing ratio at cloud base, in grams per kilogram;

W_1 = saturation mixing ratio at an evaluated level in the cloud;

P_1 = atmospheric pressure at the evaluated level within the cloud; and

T_1 = temperature (kelvin) at the evaluated flight level.

The graphs, which compensate for adjusted lapse rates, were constructed for values of LWC tabulated against cloud heights. The cumulus graph has been constructed for clouds having bases near 950 millibars; and the stratus graph, for clouds with bases near 850 millibars. Deviations for these types of clouds with bases at different levels are very slight and may be ignored. The LWC values indicated on the graph are the critical values necessary to produce the icing intensities indicated by the areas they separate. The location of the LWC lines is based on studies of moisture distribution in clouds at different levels and the typical lapse rates within those types of clouds.

When you have determined that icing exists by the Minus 8D method, locate the base of the cloud. Read the temperature at the cloud base. From the cloud base temperature, go straight up the graph to determine the maximum probable icing in the cloud for the height above the cloud base. For instance, with a stratiform cloud base temperature of 10 °C, you would evaluate no icing up to 3,000 feet or so above the cloud base, moderate icing from 3,000 feet to 5,000 feet, and severe icing from 5,000 feet upwards. Adding these values to the actual height of the cloud base will give you the heights of the probable maximum icing intensity. Figure 6-2-24 shows the maximum probable intensity of icing analysis for the example we used in the Minus 8D method. In this example, let's assume a nimbostratus cloud base at 900 millibars (3,300 feet) and a cloud base temperature of 0 °C. Using the stratus graph, we would evaluate light icing to 2,700 feet above the cloud base, with moderate icing above 2,700 feet. Since the cloud base is at 3,300 feet, the graph would tell us that the maximum probable icing in this case is light icing from 3,300 feet to 6,000 feet (3,300 + 2,700), with moderate icing from 6,000 feet upward. But the Minus 8D method shows icing only from 6,400 feet to 10,800 feet. Therefore, our analysis would combine the two techniques, resulting in moderate icing from 6,400 feet to 10,800 feet. Use the criteria presented in lesson 1 to assign a type to this icing.

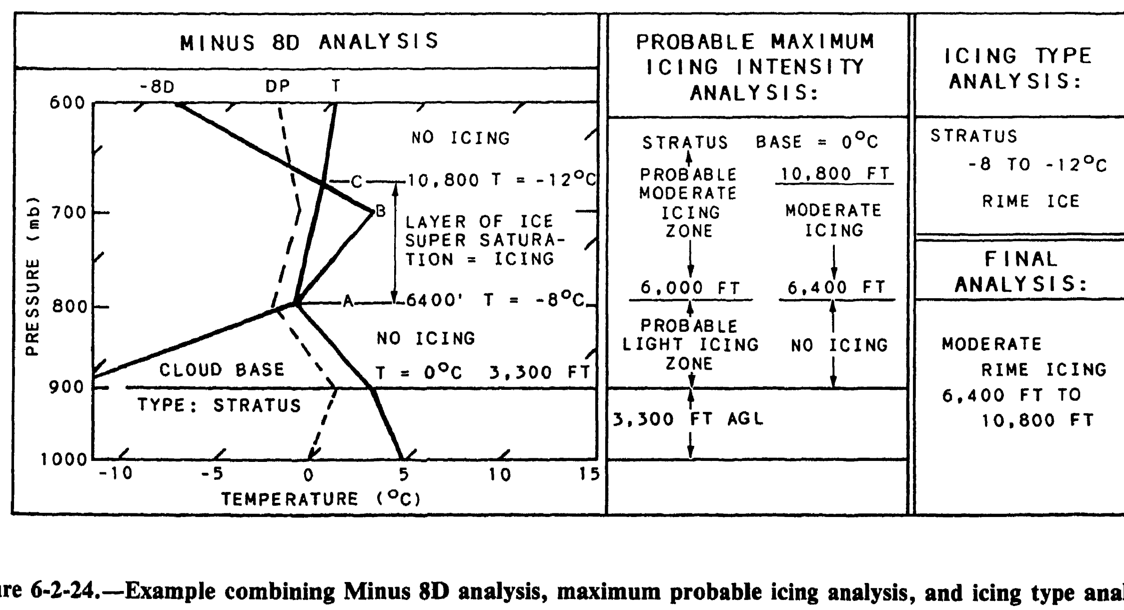


Figure 6-2-24.—Example combining Minus 8D analysis, maximum probable icing analysis, and icing type analysis.

If any doubt exists as to the probable intensity of icing occurring, you may use the formula for determining LWC and actually evaluate a level or two to find LWC. An LWC value less than 0.68 indicates light icing; between 0.68 and 1.33, moderate icing; and greater than 1.33, severe icing. Remember to determine the mixing ratio values from the frost point temperature—not the dew point temperature. Actual LWC calculations would yield values for actual icing conditions—not the maximum probable icing.

Learning Objective: Determine how the Skew T may be used to analyze frontal systems.

FRONTAL ANALYSIS ON THE SKEW T

An analyzed Skew T, Log P Diagram can be used to determine if a front has passed a station, the strength of a front, the height of a front above a station, and frontal slope.

To determine whether a front is above a station, you must examine the temperature and dew point curves. The temperature lapse rate undergoes a change through the frontal zone. It may decrease at a slower rate, becoming more isothermal, or it may increase through the zone, producing an inversion. Figure 6-2-25 illustrates lapse rate changes through frontal zones. Do not look for these changes above 400 millibars; more often than not, they are found below 500 millibars.

When there is a significant temperature contrast across a front, the front is classified as strong. Such fronts are marked by an inversion through the frontal zone. Cold fronts usually show a marked temperature inversion. When the temperature contrast across a front is small, it is classified as weak. Such fronts are marked by a temperature lapse rate that is slightly less steep through the frontal zone.

Cold fronts generally show a stronger inversion than warm fronts, and the inversion appears at successively higher levels as the front moves past a station. The reverse is true of warm fronts. Occluded fronts generally show a double inversion when they first form. Later, the temperature contrast across the occlusion lessens and the inversions are wiped out or they fuse.

When a front is accompanied by abundant cloudiness and precipitation, look for an increase in the dew point through the frontal zone (a dew point inversion). See figure 6-2-26.

When strong fronts are accompanied by little or no precipitation, it is usually due to subsidence occurring in the warm air. Subsidence (sinking air) causes warming and thereby strengthens inversions. For weather activity to increase at a front, there must be a net upward motion of the warm air mass. Rising air currents bring about cooling,

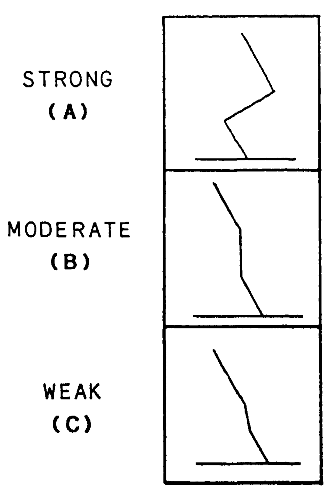


Figure 6-2-25.—Example of lapse rates through a frontal zone.

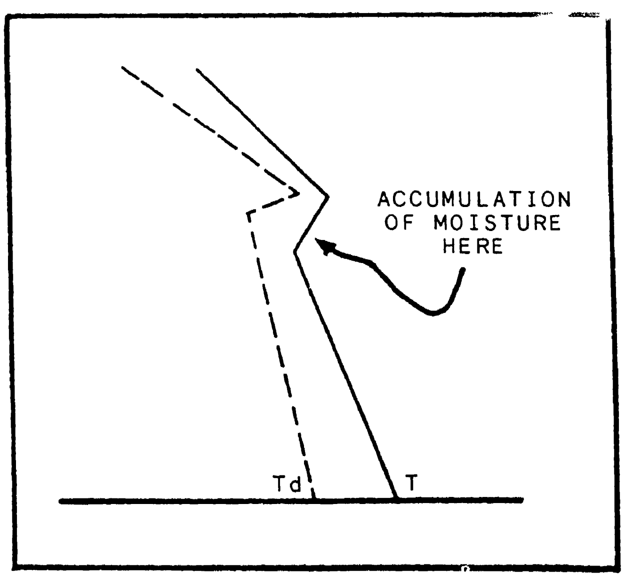


Figure 6-2-26.—Example of a dew-point inversion.

condensation, and saturation. This results in clouds and eventually precipitation.

Another determination that can be made using the data on a Skew T is the slope of a front. The slope can be determined when you know the distance to the surface front and the height of the front above the station of interest. The height of a front above a station is determined using the pressure-altitude curve. Normally, the height of the edge of the frontal zone adjacent to the warm air mass is determined. This is the FRONTAL SURFACE. For example, if a fast-moving cold

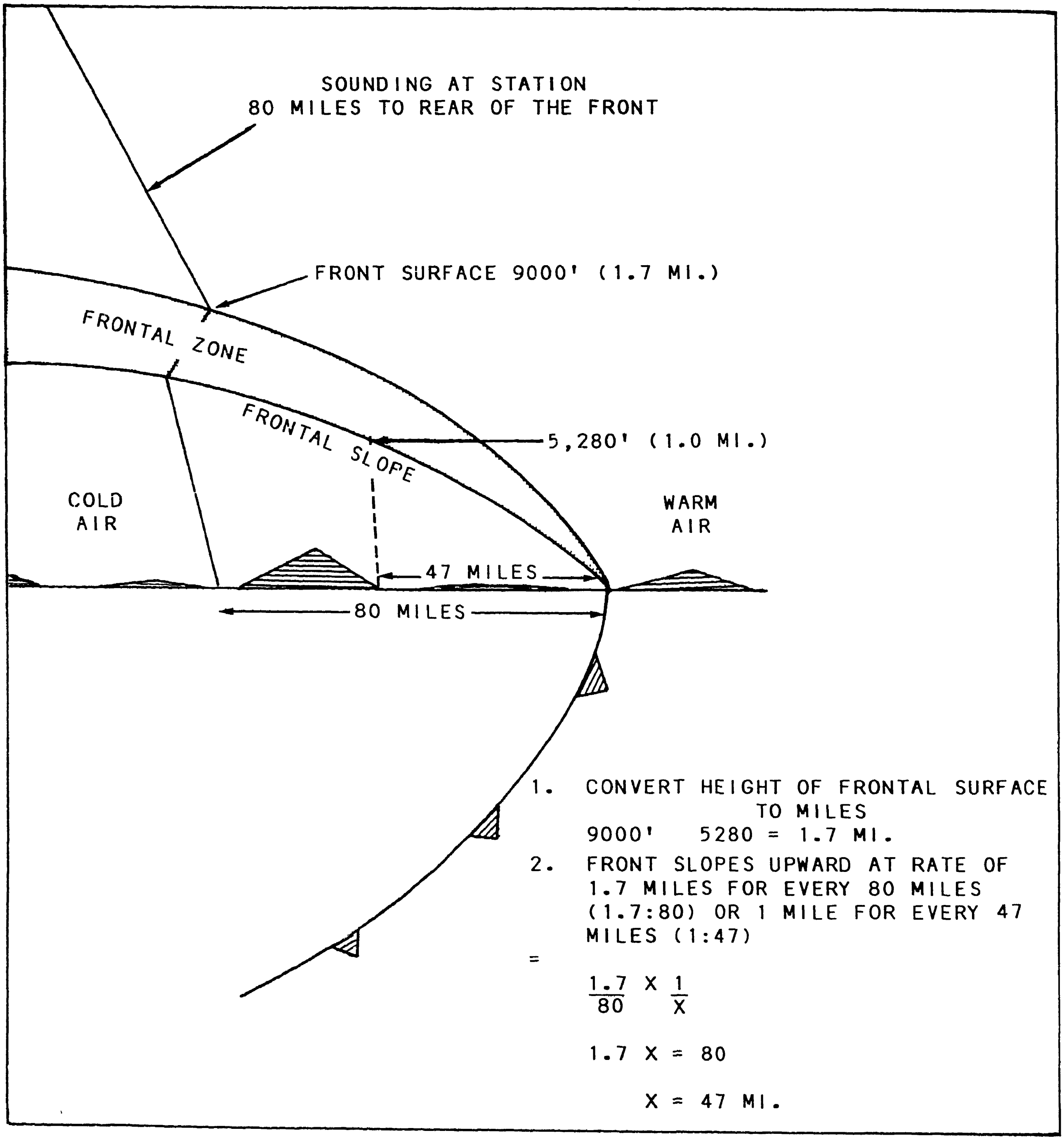


Figure 6-2-27.—Determination of frontal slope.

front's surface position is 80 miles east of your station and if the height of the frontal surface, as determined from the Skew T, is 9,000 feet above your station, you can determine the slope of the front using simple mathematics. First, convert the height of the front above the surface (9,000 feet) into miles by dividing 9,000 feet by 5,280 feet (the equivalent of 1 mile). You should get 1.7 miles (rounded off). This is the height of the frontal surface 80 miles to the rear of the surface position. From the surface position, you now know that the front rises at the rate of 1.7 miles for each 80 miles of horizontal distance, or as expressed in ratio form, 1.7:80. The horizontal distance to the point where the frontal surface is 1 mile above the surface is 47 miles. This is determined using the formula shown in figure 6-2-27.

UNIT 6—LESSON 3

REFRACTIVITY

OVERVIEW	OUTLINE
Define *refraction*, and identify the atmospheric properties that control it and the units used to measure it.	Atmospheric refraction
Identify the methods used to determine *N*-values.	Determining *N*-values
Identify the four types of refractive conditions and the effects of each on radar.	Refractive conditions
Identify the manual methods used to determine refractive conditions.	Determining refractive conditions
Identify the manual methods used to determine whether trapping conditions are occurring.	Determining the probability of trapping
Define *anomalous propagation*.	Anomalous propagation
Identify refractivity computer programs and the capabilities of each.	Refractivity computer programs
Identify the methods used to present refractive conditions.	Methods of presenting refractive conditions

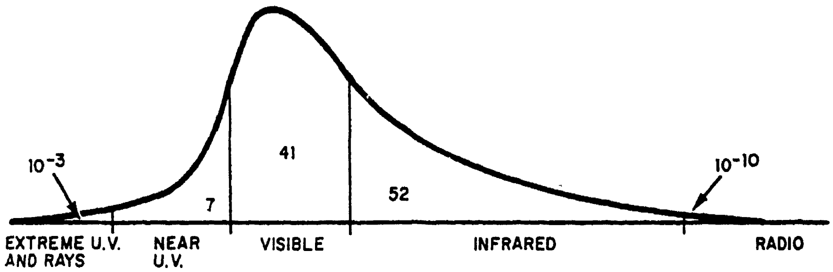
REFRACTIVITY

Electromagnetic energy (radiation) is defined as the emission and propagation of electromagnetic waves or particles through an electromagnetic field. Common examples of electromagnetic energy include light emitted from a searchlight, radio and television waves, and energy created by a microwave oven. Electromagnetic energy was previously discussed in Unit 1, Lesson 2 of the *AG2*, Volume 1. Before we go on, it may help if you review that material.

Electromagnetic energy travels in waves and is most often characterized by wavelength and frequency. Wavelengths range from .001 micrometer to 10 centimeters, while frequencies range from approximately 10 Hz to 10^{25} Hz. These ranges make up the electromagnetic spectrum. See figure 6-3-1. The electromagnetic spectrum is subdivided into eight major categories: (1) electric waves; (2) radio waves; (3) infrared; (4) optical; (5) ultraviolet; (6) X-rays; (7) gamma rays; and (8) cosmic rays.

In this lesson we will look at the radio wave portion of the electromagnetic spectrum. More specifically, we will look at the effect of the atmosphere on radar (Radio Detection And Ranging) transmissions.

The effects of the atmosphere on radar transmissions are very important, since radar is our primary means of long-range early detection of enemy aircraft, ships, missiles, and so forth.



SCHEMATIC DIAGRAM OF THE DISTRIBUTION OF ENERGY IN THE SOLAR SPECTRUM. (NOT TO SCALE). THE NUMBERS ARE PERCENTAGES OF THE SOLAR CONSTANT. THE FIGURE FOR THE RADIO ENERGY IS FOR THE OBSERVED BAND FROM 15 TO 30,000 MHZ.

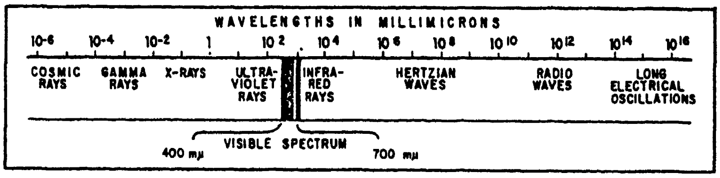


Figure 6-3-1.—Electromagnetic spectrum.

Learning Objective: Define refraction, and identify the atmospheric properties that control it and the units used to measure it.

ATMOSPHERIC REFRACTION

When a radar is radiating, electromagnetic energy in the form of radio waves is transmitted. As the waves move through the atmosphere, they often encounter layers or regions having different densities. Density differences, both vertical and horizontal, affect wave speed and direction. In some regions, the waves may speed up, while in other regions they may slow down. When one portion of a wave is slowed and another portion is not, the wave bends in the direction of the slower portion of the wave. These variations in wave velocity bend the radio waves either toward or away from Earth's surface. This bending process is called REFRACTION.

Refraction is controlled by temperature, moisture, and pressure; it is measured in "*N*-units."

TEMPERATURE—An increase in temperature causes a decrease in *N*-units. The actual ratio of change is very near one-to-one. A 1 °C increase in temperature produces a one-unit decrease in *N*, and a 1 °C decrease produces a one-unit increase in N. Latitudinally, *N*-units are higher at the poles and lower at the equator.

MOISTURE—Changes in water vapor content produce the greatest changes in refraction. The greater the moisture content in a given layer of the atmosphere, the greater the vapor pressure. Vapor pressure produces a directly proportional change in *N*. The ratio is 1 to 5; a 1-millibar increase in vapor pressure causes a 5-unit increase in *N*.

PRESSURE—Although pressure is one of the properties that control refraction, its effects are minimal. Pressure variations alone provide no significant change in refractive conditions.

N-UNITS—*N*-units are computed for various levels in the atmosphere. Like temperature, pressure, and moisture, *N*-units normally decrease with height. *N*-units are used to determine the speed of electromagnetic waves. The smaller the *N*-value, the faster the waves; the larger the *N*-value, the slower the waves.

Learning Objective: Identify the methods used to determine *N*-values.

DETERMINING N-VALUES

N-values are determined for various levels within the atmosphere by using pressure, temperature, and dewpoint values and either a refractive index nomogram or a Skew T, Log P Diagram.

Refractive Index Nomogram

The Refractive Index Nomogram is a reasonably accurate method of determining N-values. Directions are included on the nomogram. See figure 6-3-2.

Skew T, Log P Diagram

There are two methods of determining refraction from the Skew T. One method uses the modified Skew T (DOD-WPC-9-16-2), which includes a built-in refractivity grid, while the other

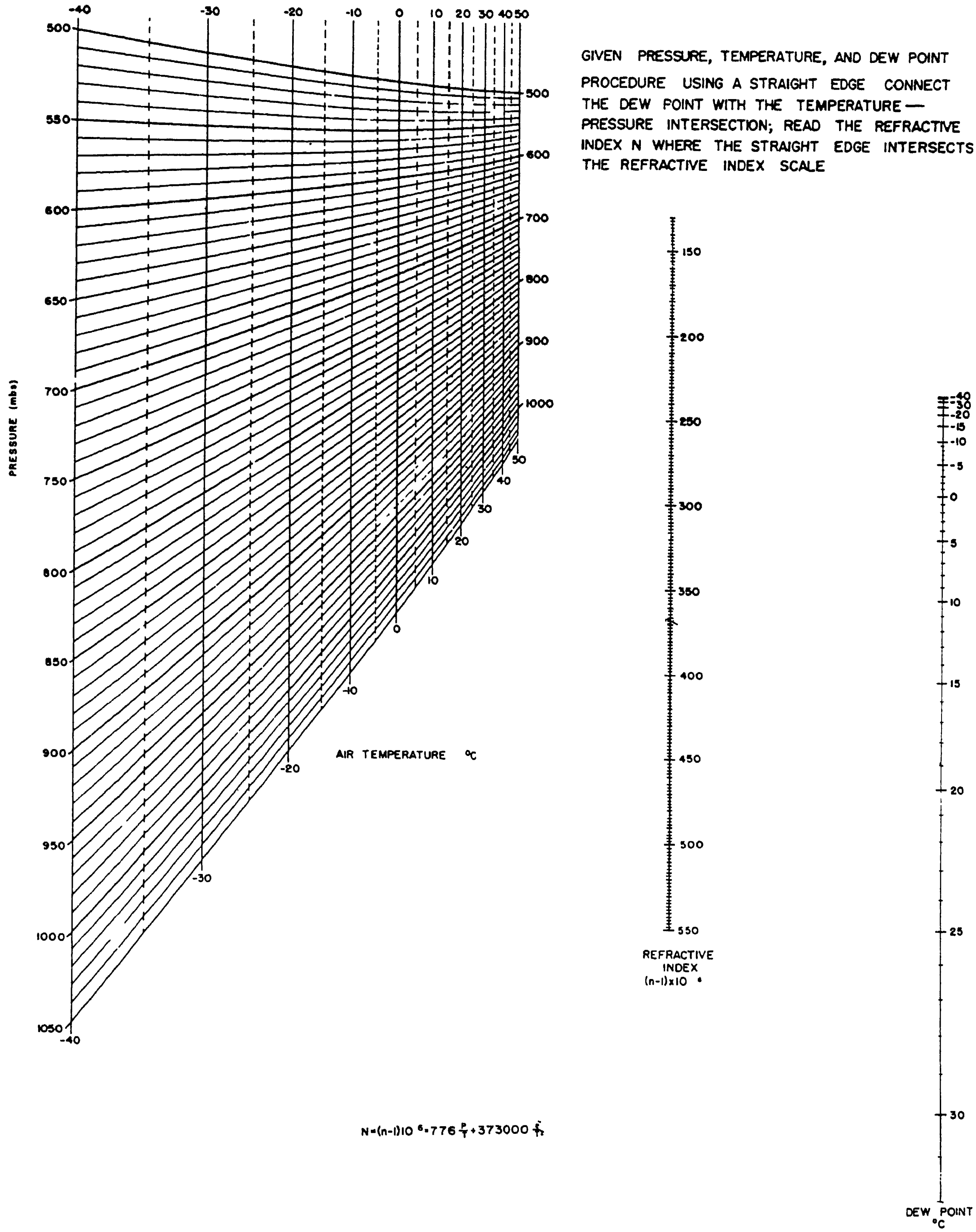


Figure 6-3-2.—Refractive Index Nomogram.

uses a standard Skew T, with a separate refractivity overlay. The overlay and the over-print on the Modified Skew T are very similar. Computations are done the same way on both.

Both Skew T methods involve computations of the *N*-value for dry air (N_d) and moist air (N_w). The overall N-value is determined by adding N_d and N_w.

N_d is represented on the refractivity grid by black, nearly horizontal lines that slope down toward the right. These lines are labeled from 350 to 40. N_d is read directly from the point of intersection with the temperature curve.

N_w is represented on the grid by black diagonal lines that slope steeply upwards toward the right. These lines are labeled across the bottom and right edge of the chart as follows: from 1 to 10, in increments of 1; from 10 to 40, in increments of 5; from 40 to 120, in increments of 10; and from 120 to 350, in increments of 20. Follow the example given in figure 6-3-3 to determine N_w for any given level; the example uses the 850-millibar level. The procedure is as follows:

1. Find the mixing ratio line that intersects the dewpoint.

2. From the temperature plot, follow the thin black line, sloping upward to the left to the point where it intersects the mixing ratio line determined in step 1.

3. Read N_w at the intersection of the thin black line and the mixing ratio line.

4. After determining N_d and N_w, add them together to obtain the value of *N*.

Learning Objective: Identify the four types of refractive conditions, and the effects of each on radar.

REFRACTIVE CONDITIONS

After *N*-units are determined, the refractive conditions can be determined. The four basic classifications of refraction are Normal, Sub-refractive, Super-refractive, and Trapping. These classifications are based on refractive conditions in the atmosphere.

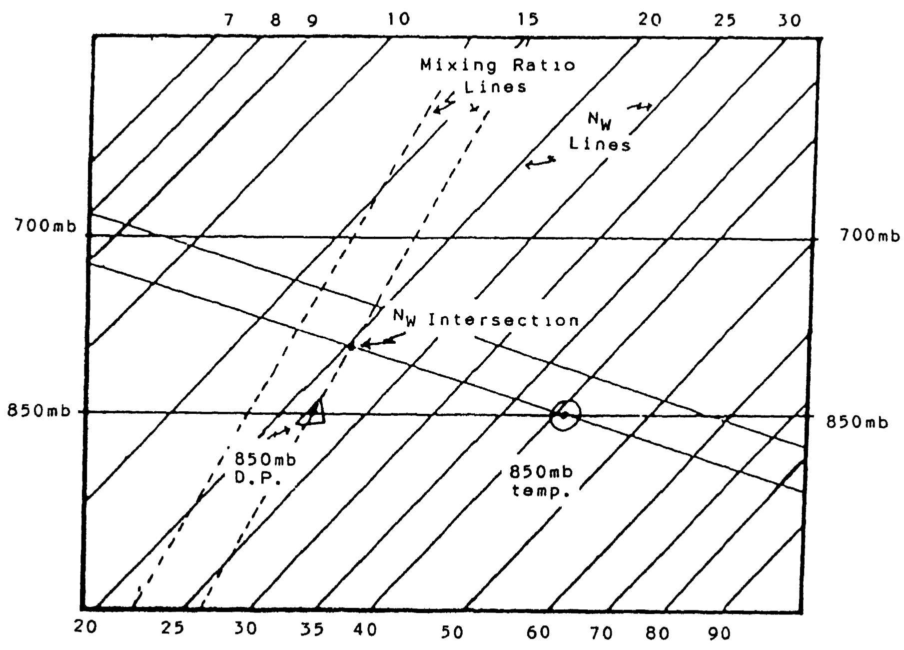


Figure 6-3-3.—The Skew T refractive overlay and over-print.

For effective evaluation of refractive conditions, changes in *N* over known vertical distances are required. This is the reason for computing N-units at different levels in the atmosphere. Determining *change in N with height* is known as computing the N-gradient.

Normal-Refraction Conditions

Under NORMAL-REFRACTION conditions, N decreases with height at a rate between 0 and −24 *N*-units per 1,000 feet. The normal N-gradient overland shows a decrease of 12 *N*-units per 1,000 feet; while over water, *N* decreases at a rate of 18 *N*-units per 1,000 feet. When there is no change in *N*-values (0 *N*-units per 1,000 feet), there is no refraction; the radar waves travel in a straight line. As the gradient decreases toward −24 *N*-units per 1,000 feet, the radar waves bend increasingly downward, toward Earth's surface. Figure 6-3-4 illustrates the effect normal-refraction conditions have on radar.

Subrefraction Conditions

When SUBREFRACTION conditions occur, *N* increases with height (a positive N-gradient). Subrefraction conditions cause electromagnetic waves to bend upward, into the atmosphere.

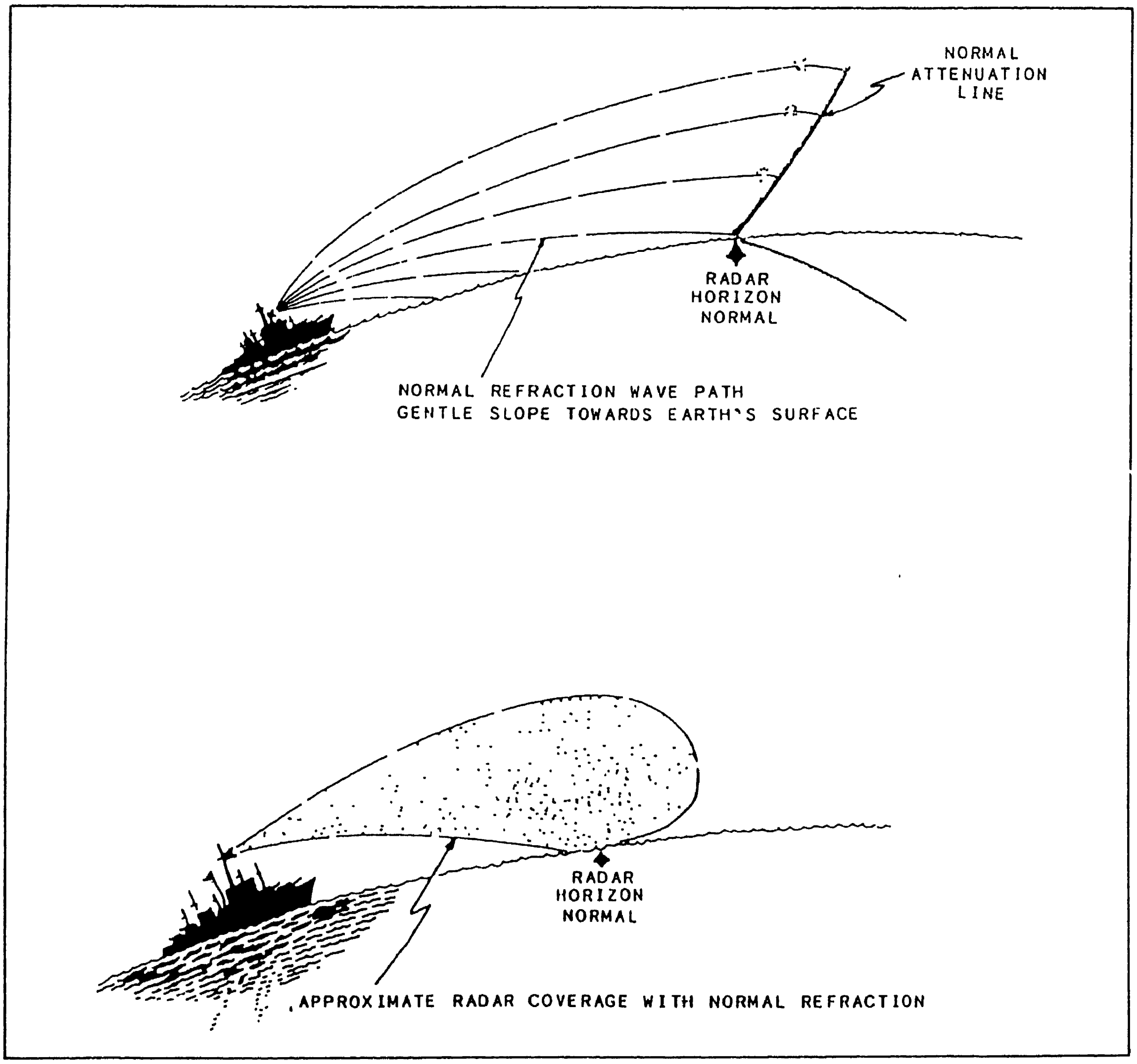


Figure 6-3-4.—Effect of normal-refraction conditions on radar.

See figure 6-3-5. The stronger the gradient, the greater the degree of bending. Radar ranges are significantly reduced under these conditions.

Superrefraction Conditions

When *N* decreases at a rate of −24 to −48 *N*-units per 1,000 feet, a SUPERREFRACTION condition exists. In this situation, the radar waves bend downward at a much faster rate than they do under normal conditions. Figure 6-3-6 illustrates the superrefraction condition.

Trapping Conditions

When the N-gradient is −48 N-units per 1,000 feet or greater, a condition known as TRAPPING occurs. With trapping, the refraction is extreme. The temperature and moisture conditions are such that the electromagnetic waves are sharply refracted back to the surface, where they are reflected back into the trapping zone. This process is repeated over and over. Little energy is lost in this process, and radar ranges are significantly extended when trapping conditions occur. Figure 6-3-7 illustrates the effect of trapping on radar.

Learning Objective: Identify the manual methods used to determine refractive conditions.

DETERMINING REFRACTIVE CONDITIONS

Refractive conditions can be determined manually by constructing an N-profile (curve) and

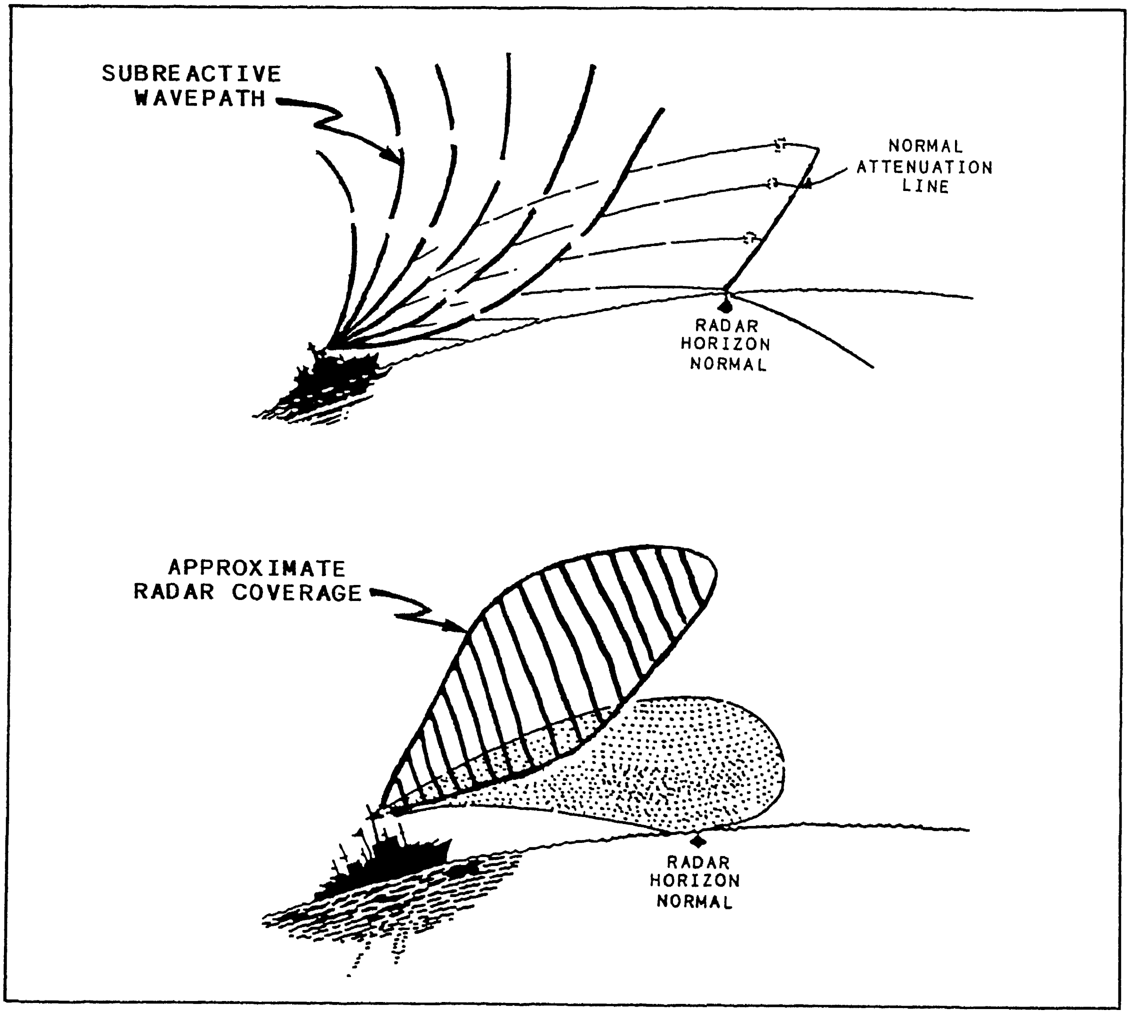


Figure 6-3-5.—Comparison of a subrefractive wave path to a normal wave path.

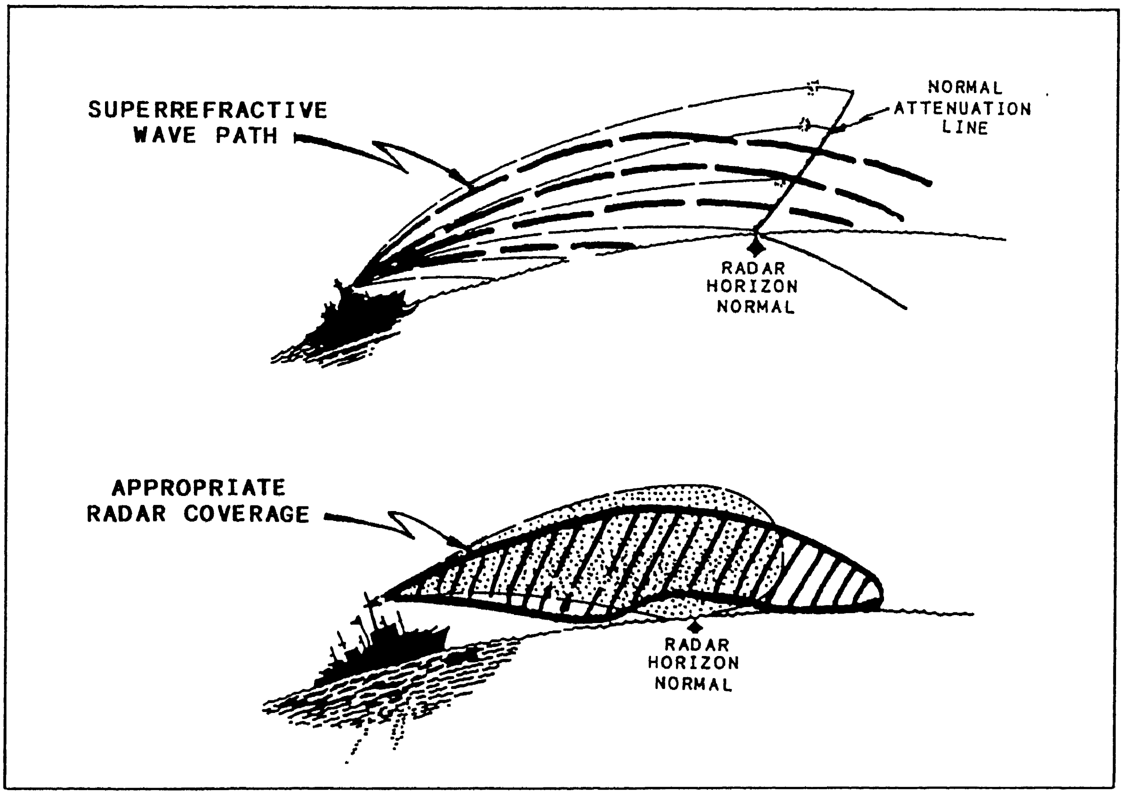


Figure 6-3-6.—Comparison of superrefractive wave path to normal wave path.

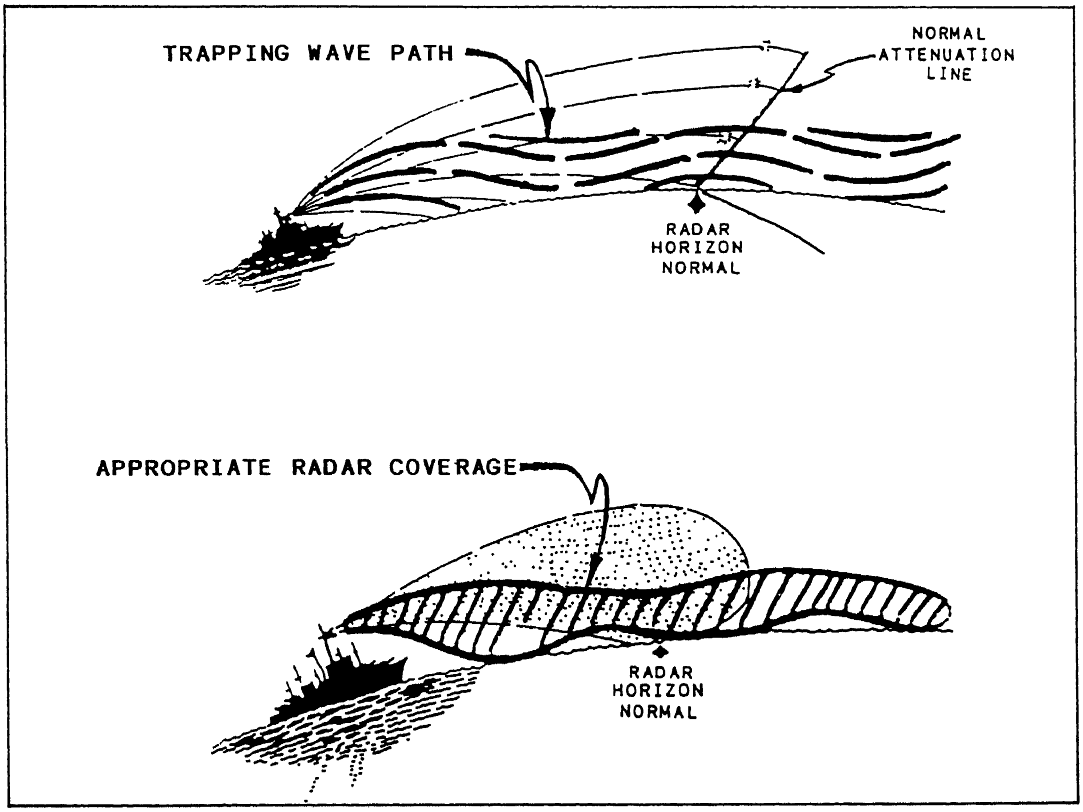


Figure 6-3-7.—Comparison of trapping wave path to normal wave path, and approximate difference in radar coverage.

overlaying it with an N-gradient overlay, or by working up the data on a refractive index worksheet.

N-Profile

An N-profile is simply a graphic presentation of N in the vertical. The profile is sometimes referred to as the N-curve or trace. It is constructed on graph paper, using the height of the *N*-values and the *N*-values themselves. See figure 6-3-8. Note that the heights are displayed vertically along the left side of the graph and the *N*-values are displayed horizontally along the bottom. After plotting all of the N-values, connect the values. Compute N-gradients for every layer, starting at the surface. Color code the zones or layers of subrefraction, superrefraction, and trapping conditions; shade subrefraction zones blue, superrefraction zones green, and trapp zones red.

N-Gradient Overlay

After plotting the N values on the N-prof use the N-gradient overlay to quickly determ refractive conditions without computing gradiei The overlay is shown in figure 6-3-9. Use it follows:

1. Place the N-gradient overlay on the gra so the intersection of the *N*-reference line and *h*-reference line is on the plotted *N*-value at base of the layer with which you are worki Align the *N*-reference line with the height line the graph, as shown in figure 6-3-10.
2. Determine the refractivity for the layei question. For example, in figure 6-3-10,

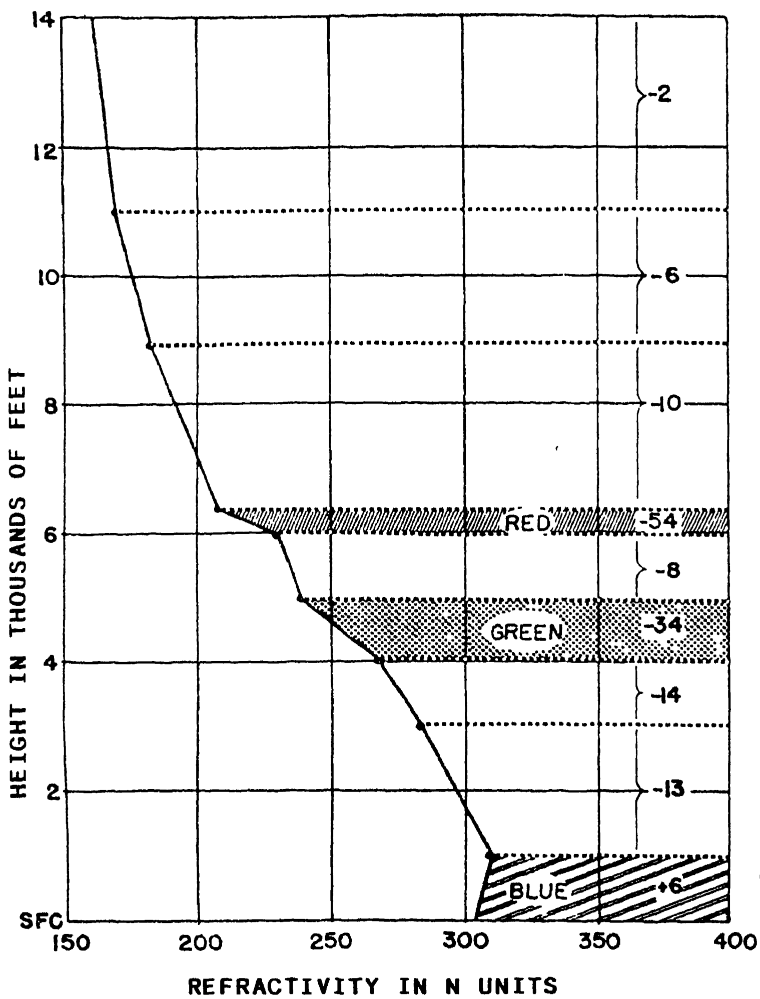


Figure 6-3-8.—Analyzed N-profile.

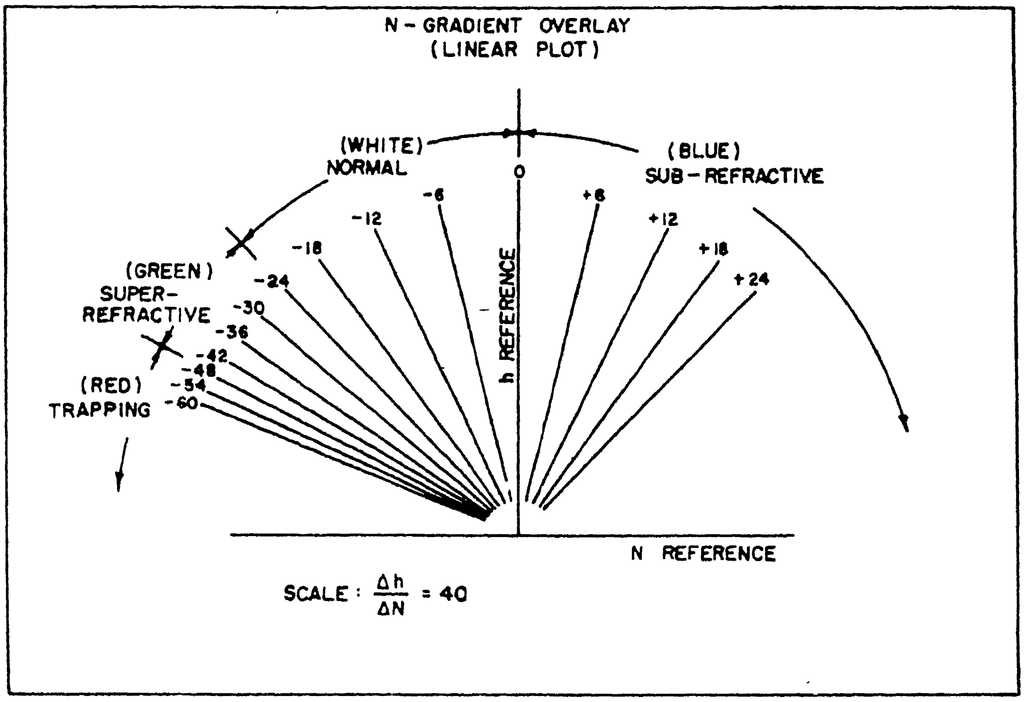


Figure 6-3-9.—N-gradient overlay.

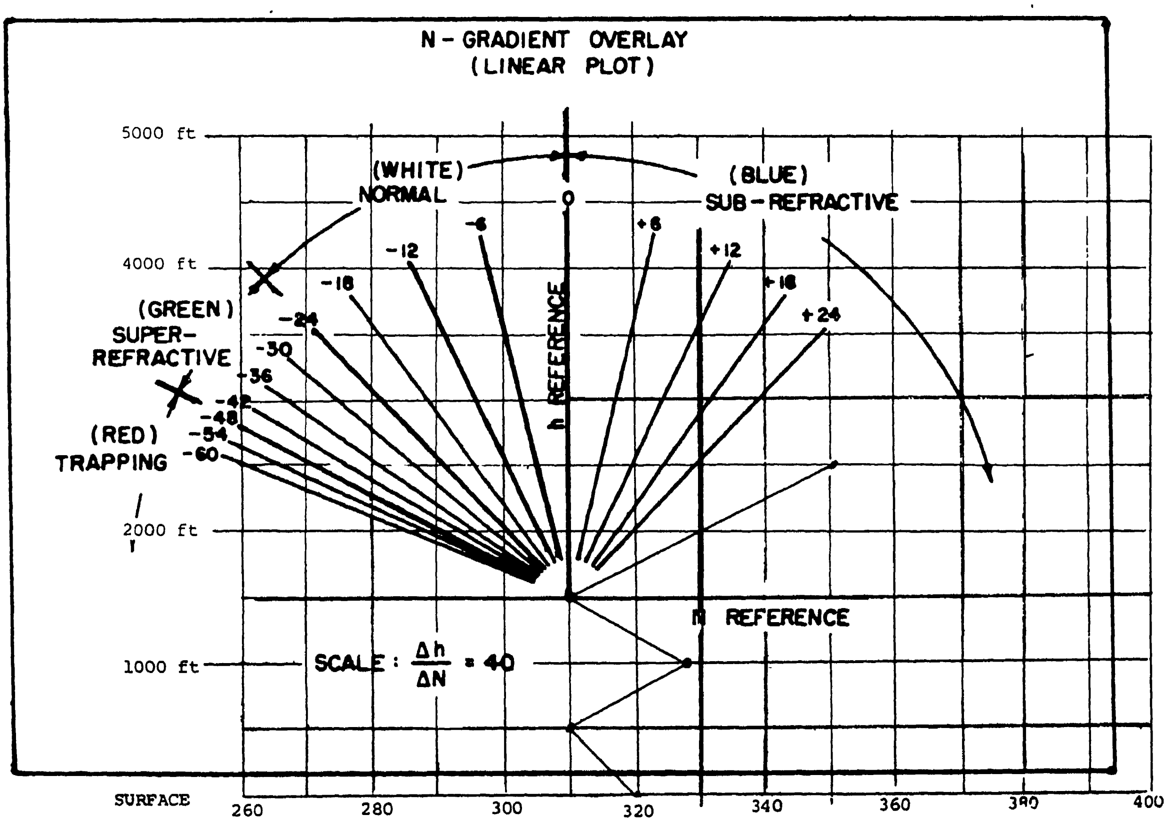


Figure 6-3-10.—N-gradient overlay on graph.

conditions in the layer from 1,500 to 2,000 feet are subrefractive.

Refractive Index Worksheet

Figure 6-3-11 is an example of a refractive index worksheet. Use the worksheet, in conjunction with an upper-air sounding, to provide a quick reference to all of the data used in refractivity computations. Complete the worksheet as follows:

PRESSURE COLUMN—Enter surface, mandatory, and significant levels through 500-millibars.

HEIGHT—Enter height, in feet, of all mandatory levels. Remember, heights in the radiosonde code are encoded in meters. To convert meters into feet, multiply the height in meters by 3.3 feet. Next, estimate the height values of all significant levels. This is done using the "feet per millibar" conversion factor: 45 feet = 1 millibar. For example, to find the height of the significant level at 565 millibars, find the difference, in millibars, between 565 and the closest mandatory level. The closest mandatory level to 565 millibars is the 500-millibar level. 565 − 500 = 65 millibars. Multiply the difference (65 millibars) by 45 feet (the conversion factor). This gives a conversion figure of 2,925 feet. Next, simply subtract the 2,925 feet from the height of the 500-millibar level. This gives you an approximate height of the 565-millibar level.

TEMPERATURE—Enter the temperature in degrees Celsius.

DEW POINT—Enter the dew point in degrees Celsius.

N-UNITS—Compute N-units for each level, using the Refractive Index Nomogram or Skew T.

LAYER THICKNESS—Enter, in feet, the difference between each height for which *N* was computed.

N-DIFFERENCE—Enter the difference in *N*-units between each level. Label these values with a + or − to indicate an increase or a decrease with height.

N-GRADIENT—Enter the N-gradient per 1,000 feet by dividing the N-difference by the layer thickness for each layer. Round off to the nearest whole number. For example, if *N* decreases 42 *N*-units in a layer 560 feet, you must figure out the decrease per 1,000 feet. Using the ratio formula ***42 is to 560 as X is to 1,000***, we see that the gradient is 75 N-units per 1,000 feet.

$$\frac{42}{560} = \frac{X}{1{,}000}$$

$$560X = 42{,}000$$

$$X = 75$$

CLASSIFICATION—Enter the refractive classification for each level according to the N-gradient value.

Learning Objective: Identify the two manual methods of determining whether trapping conditions are occurring at your ship.

DETERMINING THE PROBABILITY OF TRAPPING

At sea, in certain parts of the world, trapping occurs with almost predictable regularity. When trapping occurs, certain combinations of atmospheric conditions are nearly always present:

- Temperature increases with height
- Moisture decreases with height

Occasionally, deviations from these two basic conditions do occur. The temperature can decrease with height as long as there is a sharp decrease in moisture with height.

Understanding the relationship between refractivity and the changes in moisture and temperature will enable you to make reasonable estimates on the occurrence of trapping.

There are two manual methods of determining whether trapping conditions exist at your ship. The first method is simply an estimate, while the second method (the ductogram) is much more accurate.

REFRACTIVE INDEX WORKSHEET

PRESSURE	HEIGHT (FEET)	TEMP. (C)	DEW PT. (C)	N-UNITS	LAYER THICKNESS	N-DIFF.	N-GRAD.	CLASS.

INSTRUCTIONS

1. PRESSURE: Enter surface and all mandantory and significant levels thru 500 mbs from sounding.

2. HEIGHT: Enter height in feet of all levels. Convert meters to feet for mantantory levels. Estimate height values for significant levels using the feet per mb. conversion factor. For example:
1) 564-500 = 64 mbs X 45 = 2880 ft.
2) 500 mb ht. - 2880 ft = 564 mb ht.

3. TEMP: Enter temperature in C.

4. DEW PT. : Enter dewpoint in C.

5. N-UNITS: Using Refractive Index Nomogram, compute N-units for each level.

6. LAYER THICKNESS: Enter, in feet the difference between each level. Move decimal point 3 places to the left for each value. For example, 338 = .338 .

7. N-DIFF: Enter difference in N-units between each level. Label these values + or - to indicate increase or decrease with height.

8. N-GRAD: Enter N-gradient per 1000 feet by dividing N-DIFF column by LAYER THICKNESS column for each layer. Round off to nearest whole number.

9. CLASS: Enter refractive classification for each level according to N-gradient values.

HEIGHT DIFFERENCE PER MB IN FEET

1000 - 850 : 29   850 - 700 : 34
700 - 600 : 39   600 - 500 : 45

SUB-REFRACTIVE··· N increases with height
NORMAL ·········· 0 to -24 N-units per 1000 ft.
SUPER-REFRACTIVE· -24 to -48 N-units per 1000 ft.
TRAPPING········· -48 or greater

Figure 6-3-11.—Refractive Index Worksheet.

Estimating Trapping Conditions

The trapping estimation procedure uses air-temperature- and sea-surface-temperature (SST) readings, as well as the saturation vapor pressure at the sea surface and at the observation level. The procedure is as follows:

1. Obtain the current air temperature (T_A) and sea-surface temperature (T_S), in degrees Celsius.
2. Determine the difference between T_A and T_S. Remember, a 1 °C increase in temperature causes a decrease in N by 1 unit, while a 1 °C decrease causes an increase in N by 1 unit.
3. Using T_A and T_S, determine the saturation vapor pressure for each. Saturation vapor pressures can be computed or taken from a table. Since the use of a table is much easier, refer to table 6-3-1. Find the saturation vapor pressure for an air temperature of 27 °C and a SST of 20 °C. You should come up with 36-millibars and 23-millibars (rounded off), respectively. Table 6-3-1 is a partial table taken from the *Smithsonian Meteorological Tables*.
4. Determine the difference in vapor pressure between the sea surface and the air-temperature observation level. Remember, the vapor pressure to N-unit ratio is 1 to 5.
5. Algebraically add the N-units as determined in steps 3 and 4. For example, let's assume that the temperature difference causes a 4 unit increase in N (+4) and that the vapor pressure difference causes a 15 unit decrease in N (−15). By adding +4 and −15, you should come up with −11 N-units.
6. Determine the refractive condition based on the N-gradient. For example, if the height difference between the sea surface and the observation level is 100 feet and we determine that N decreases 11 units over this distance, the gradient is −11 N-units per 100 feet, or −110 N-units per 1,000 feet. Since trapping conditions occur when N decreases at a rate of −48 N-units per 1,000 feet or greater, we can assume that trapping conditions are occurring.

This method provides an ESTIMATE ONLY because of certain limitations and assumptions. We assume that the SST is the same as the air directly above the sea. If an air temperature reading could be taken directly at sea level, this reading would be used. However, obtaining an air temperature reading at sea level while on a moving ship is not possible. Also, we are limited to a true surface reading (no injection readings). Sea-water injection temperatures should not be used, because they can differ from true surface temperatures by several degrees. Another assumption concerns vapor pressure. The difference in vapor pressure between the observation deck and the sea surface is assumed to be linear (a straight-line difference), but in reality, vapor pressures can be quite varied over these distances.

Ductogram

One very accurate method of determining the occurrence of trapping is through use of the ductogram. The ductogram uses temperature and dew-point readings taken at the bridge or flight deck level, as well as sea-surface temperature (SST) readings.

Since trapping criteria differ based on various wavelengths and radar types, separate diagrams are required for each different frequency band. The ductogram and diagrams, along with instructions on their use, can be found in Appendix III.

Learning Objective: Define *anomalous propagation.*

ANOMALOUS PROPAGATION

Anomalous propagation (AP) refers to abnormal refraction of electromagnetic energy. AP occurs when the atmospheric conditions cause electromagnetic energy to arrive at a destination(s) via a path(s) significantly different from a normally expected path(s). AP is most likely to occur when subrefraction, superrefraction or trapping conditions occur, because these conditions create the greatest amount of refraction.

When AP is present, strange radar images occur. For example, radar operators report targets at far greater ranges than would normally be expected. They report echoes on radar screens when there is nothing in the atmosphere to produce echoes (such echoes are referred to as "false echoes" or "ghost targets"). They report no contacts (echoes) but visual surveillance indicates otherwise. This latter type of occurrence is due to a "blind spot" or "radar hole" in radar coverage.

Table 6-3-1.—Saturation Vapor Pressure Over Water

Metric units

Temperature	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
°C.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.
0	6.1078	6.1523	6.1971	6.2422	6.2876	6.3333	6.3793	6.4256	6.4721	6.5190
1	6.5662	6.6137	6.6614	6.7095	6.7579	6.8066	6.8556	6.9049	6.9545	7.0044
2	7.0547	7.1053	7.1562	7.2074	7.2590	7.3109	7.3631	7.4157	7.4685	7.5218
3	7.5753	7.6291	7.6833	7.7379	7.7928	7.8480	7.9036	7.9595	8.0158	8.0724
4	8.1294	8.1868	8.2445	8.3026	8.3610	8.4198	8.4789	8.5384	8.5983	8.6586
5	8.7192	8.7802	8.8416	8.9033	8.9655	9.0280	9.0909	9.1542	9.2179	9.2820
6	9.3465	9.4114	9.4766	9.5423	9.6083	9.6748	9.7416	9.8089	9.8765	9.9446
7	10.013	10.082	10.151	10.221	10.291	10.362	10.433	10.505	10.577	10.649
8	10.722	10.795	10.869	10.943	11.017	11.092	11.168	11.243	11.320	11.397
9	11.474	11.552	11.630	11.708	11.787	11.867	11.947	12.027	12.108	12.190
10	12.272	12.355	12.438	12.521	12.606	12.690	12.775	12.860	12.946	13.032
11	13.119	13.207	13.295	13.383	13.472	13.562	13.652	13.742	13.833	13.925
12	14.017	14.110	14.203	14.297	14.391	14.486	14.581	14.678	14.774	14.871
13	14.969	15.067	15.166	15.266	15.365	15.466	15.567	15.669	15.771	15.874
14	15.977	16.081	16.186	16.291	16.397	16.503	16.610	16.718	16.826	16.935
15	17.044	17.154	17.264	17.376	17.487	17.600	17.713	17.827	17.942	18.057
16	18.173	18.290	18.407	18.524	18.643	18.762	18.882	19.002	19.123	19.245
17	19.367	19.490	19.614	19.739	19.864	19.990	20.117	20.244	20.372	20.501
18	20.630	20.760	20.891	21.023	21.155	21.288	21.422	21.556	21.691	21.827
19	21.964	22.101	22.240	22.379	22.518	22.659	22.800	22.942	23.085	23.229
20	23.373	23.518	23.664	23.811	23.959	24.107	24.256	24.406	24.557	24.709
21	24.861	25.014	25.168	25.323	25.479	25.635	25.792	25.950	26.109	26.269
22	26.430	26.592	26.754	26.918	27.082	27.247	27.413	27.580	27.748	27.916
23	28.086	28.256	28.428	28.600	28.773	28.947	29.122	29.298	29.475	29.652
24	29.831	30.011	30.191	30.373	30.555	30.739	30.923	31.109	31.295	31.483
25	31.671	31.860	32.050	32.242	32.434	32.627	32.821	33.016	33.212	33.410
26	33.608	33.807	34.008	34.209	34.411	34.615	34.820	35.025	35.232	35.440
27	35.649	35.859	36.070	36.282	36.495	36.709	36.924	37.140	37.358	37.576
28	37.796	38.017	38.239	38.462	38.686	38.911	39.137	39.365	39.594	39.824
29	40.055	40.287	40.521	40.755	40.991	41.228	41.466	41.705	41.945	42.187
30	42.430	42.674	42.919	43.166	43.414	43.663	43.913	44.165	44.418	44.672
31	44.927	45.184	45.442	45.701	45.961	46.223	46.486	46.750	47.016	47.283
32	47.551	47.820	48.091	48.364	48.637	48.912	49.188	49.466	49.745	50.025
33	50.307	50.590	50.874	51.160	51.447	51.736	52.026	52.317	52.610	52.904
34	53.200	53.497	53.796	54.096	54.397	54.700	55.004	55.310	55.617	55.926
35	56.236	56.548	56.861	57.176	57.492	57.810	58.129	58.450	58.773	59.097
36	59.422	59.749	60.077	60.407	60.739	61.072	61.407	61.743	62.081	62.421
37	62.762	63.105	63.450	63.796	64.144	64.493	64.844	65.196	65.550	65.906
38	66.264	66.623	66.985	67.347	67.712	68.078	68.446	68.815	69.186	69.559
39	69.934	70.310	70.688	71.068	71.450	71.833	72.218	72.605	72.994	73.385
40	73.777	74.171	74.568	74.966	75.365	75.767	76.170	76.575	76.982	77.391
41	77.802	78.215	78.630	79.046	79.465	79.885	80.307	80.731	81.157	81.585
42	82.015	82.447	82.881	83.316	83.754	84.194	84.636	85.079	85.525	85.973
43	86.423	86.875	87.329	87.785	88.243	88.703	89.165	89.629	90.095	90.564
44	91.034	91.507	91.981	92.458	92.937	93.418	93.901	94.386	94.874	95.363
45	95.855	96.349	96.845	97.343	97.844	98.347	98.852	99.359	99.869	100.38
46	100.89	101.41	101.93	102.45	102.97	103.50	104.03	104.56	105.09	105.62
47	106.16	106.70	107.24	107.78	108.33	108.88	109.43	109.98	110.54	111.10
48	111.66	112.22	112.79	113.36	113.93	114.50	115.07	115.65	116.23	116.81
49	117.40	117.99	118.58	119.17	119.77	120.37	120.97	121.57	122.18	122.79
50	123.40	124.01	124.63	125.25	125.87	126.49	127.12	127.75	128.38	129.01

A radar hole is an area of the atmosphere through which little or no electromagnetic energy penetrates. These holes or blind spots are produced when energy waves, traveling at different speeds through various layers of the atmosphere, are diverted from their normal path. Radar holes occur at the boundary between different propagation paths. The radar waves do not effectively penetrate these areas, and planes or missiles inside a radar hole can go undetected. Radar blind spots may be compared to the "shadow zones" encountered in sonar searches of the oceans.

The existence and dimensions of radar holes can be manually determined using graphs and formulas, or they can be computed using computer programs, such as the Integrated Refractive Effects Prediction System (IREPS) and the Refractive Index (RIA). Because of the widespread availability of these computer programs, you will most likely never have to perform the manual calculations. However, I have included them in Appendix IV so that you will have a better understanding of atmospheric refraction and what goes into these computer programs.

Learning Objective: Identify the fastest method of computing refractivity, and describe the capabilities of related refractivity computer programs.

REFRACTIVITY COMPUTER PROGRAMS

Having a computer compute refractive conditions is definitely faster than doing it by any of the other previously discussed methods. Programs to compute refractivity are available through the Geophysics Fleet Mission Program Library (GFMPL).

In addition to programs that compute refractivity, there are numerous other programs related to refractivity. Different programs are available dependent on the type of computer system used.

The following list contains the names and descriptions of some of the refractivity programs available for the HP-9020, HP-9845 Option 275, and Zenith Z-120 desk top computers:

NAME	DESCRIPTION
RIA	This program processes radiosonde data, determines thermodynamic indices, and computes refractive index profiles.
COVER	This program provides the capability to determine how a given electromagnetic system will perform under given atmospheric conditions in detecting or communicating with a given target or receiver. It displays detection or communications coverage in a vertical plane.
LOSS	This program assesses the performance of a user-specified electromagnetic system under given atmospheric conditions. It provides electromagnetic path LOSS versus range.
ESM	This program is capable of determining the probable effectiveness of various U.S. ESM receivers against a predefined set of both U.S. and Soviet emitters. It computes the maximum intercept range of surface-based ESM receivers for detection of predefined surface-system emitters under user-specified environmental conditions.
ECM	The Electronic Counter Measures program is capable of determining the optimum locations and flight paths of attack and tactical jamming aircraft. The program evaluates the effectiveness of a jamming device against an enemy radar under given atmospheric conditions.
SSR	This program determines detection ranges for surface search radars against predefined surface targets under user-specified atmospheric conditions.
HEPC	This program generates a Historical Electromagnetic Propagation Conditions summary or a profile for a user-specified location and time of year (month).

The IREPS program is not listed in the GFMPL library; however, an advanced IREPS program is available with the Tactical Environmental Support System found onboard most of our major carriers and battleships. I strongly recommend that whatever type of computer your command uses, you familiarize yourself with its capabilities and those of the above listed programs.

METHODS OF PRESENTING REFRACTIVE CONDITIONS

Pilots and radar operators are the primary users of refractive data, and as it is with almost all environmental products, we must put the data in a format that is easy to read and understand. Always include the actual figure for the N-gradient and give the zone in which the gradient is occurring. For example, −18 *N*-units per 1,000 feet from the surface is 2,500 feet.

Some of the products that we pass onto the user, other than those that are computer generated, are the N-curve graph and the refractive index worksheet. Since the worksheet contains computational data and user data, you should highlight the user information.

PRACTICAL TRAINING EXERCISE

It is now time to apply the information that you have received. Read Appendix IV and complete the exercise in the Appendix. Write down any questions you may have on the material, and go over your questions with your training petty officer, immediate supervisor, or chief.

UNIT 6—LESSON 4

ELECTROOPTICS

OVERVIEW	OUTLINE
dentify the visible portion of the electromagnetic pectrum, and the processes within the atnosphere that affect it.	Effects of the atmosphere and Earth's surface on electromagnetic energy
dentify the four factors affecting target detection.	Target detection
Name the various types of target acquisition ystems, and identify the most proficient system.	Target acquisition systems
dentify the two major components of precision guided munitions (PGMs).	Precision guided munitions
dentify the advantages and disadvantages of PGMs.	Advantages and disadvantages of PGMs

ELECTROOPTICS

In this lesson, we will take a close look at the effects the atmosphere and Earth's surface has on he visible portion of the electromagnetic spectrum and the systems that use electrooptics.

Electrooptics is another subject that deals with he electromagnetic spectrum. It is defined as that branch of physics that deals with the influence of an electric field upon light crossing the field.

The most common form of electrooptical equipment is the television. Electrooptical sensors are used in many of today's bombs and missiles. Such bombs and missiles are known as precision guided munitions (PGMs).

The ability of PGMs to hit a target is dependent on a number of factors, one of which is the environmental conditions between the PGM and ts target. PGMs employ various sensors to locate and track targets and to guide PGMs to their targets. The effects of the environment on PGMs and their sensors is the basis for this lesson.

The forecast weather for a target area may be the deciding factors in whether to use PGMs. Over a target area, pilots are kept extremely busy when the weather is unfavorable. They must spend considerable time trying to locate and lock on targets in poor weather. This is in addition to flying their craft, and trying to avoid enemy aircraft and ground defenses.

Learning Objective: Identify the visible portion of the electromagnetic spectrum, and the processes within the atmosphere that affect it.

EFFECTS OF THE ATMOSPHERE AND EARTH'S SURFACE ON ELECTROMAGNETIC ENERGY

The Sun is our primary source of electromagnetic energy. This energy moves through free space in waves that have a wide range of frequencies and wavelengths. Most of the energy

reaching Earth's lower atmosphere is at visible and near infrared wavelengths. The wavelengths of visible radiation extend from 0.4 to 0.78 microns. A micron is equal to 0.0001 cm. Radiation occurring in the 0.4 to 0.78-micron range is visible to us only because our eyes are sensitive to these wavelengths, and our brain interprets what the eyes see.

The affect of the atmosphere on the visible spectrum differs depending on the state of the atmosphere. For example, on a cloud-free day with no haze or smoke present, the Sun appears white and the sky blue. When haze and smoke are present on a cloud-free day, the Sun's appearance becomes indistinct, and the sky appears bright white. Such visible changes to the Sun's energy are caused by four atmospheric processes: reflection, scattering, absorption, and emission.

REFLECTION—Reflection of electromagnetic energy occurs at all wavelengths, although it is most readily perceivable in the visible spectrum. Reflection occurs when the wavelength of the radiation is smaller than the atmospheric elements it encounters. Clouds which are made up of varying percentages of water vapor and hygroscopic nuclei, are the primary reflectors of radiation in the atmosphere.

SCATTERING—Scattering is dependent on the wavelength of the radiated energy and the size of the particles, gas molecules, or atoms the radiation encounters in the atmosphere. When the elements in the atmosphere are smaller in diameter than the wavelength of the radiation striking them, the radiation is scattered or deflected. Elements that are larger than the wavelength of the radiation striking them DO NOT produce scattering. There are two types of scattering: Rayleigh and Mie.

Rayleigh scattering occurs when sunlight is dispersed by molecules in the atmosphere that are much smaller than the light's wavelength. Rayleigh scattering produces our blue skies on cloud-free days.

Mie scattering occurs when sunlight is deflected by elements in the atmosphere whose sizes are near that of the wavelength of the light it is scattering. Dust, haze, smoke, and cloud droplets cause Mie scattering, and the scattering causes the sky to appear white.

Scattering, especially that caused by haze (aloft and/or at the surface) adds greatly to the problem of target acquisition through reduced visibilities.

ABSORPTION—Many atmospheric elements (mainly water vapor, carbon dioxide, and oxygen) absorb radiation propagating through the atmosphere without scattering or reflecting it. Absorption occurs selectively with respect to wavelength, and each atmospheric element characteristically absorbs in specific wavelength intervals called absorption bands. For example, ozone in the upper atmosphere absorbs only ultraviolet radiation; radiation at other wavelengths is not absorbed by the ozone.

In addition to band absorption, certain atmospheric gases exhibit a characteristic described as continuum absorption. They absorb energy over a wide range of the electromagnetic spectrum. Water vapor is the most important gas with respect to continuum absorption. Continuum absorption by water vapor is most significant in an atmosphere having high or ABSOLUTE HUMIDITY. The tropics has such an atmosphere. Cold atmospheres with high relative humidity do NOT exhibit continuum absorption, because of their low water vapor content.

The ratio of the amount of radiation absorbed by a substance (for example, ozone or water vapor) to the total amount of radiation striking the substance is known as Absorptivity. Absorptivity varies with the wavelength of the radiation striking a body and the temperature of the absorbing body. No substance absorbs all of the radiation striking it; however, there are substances that approach perfect absorptivity; they absorb nearly all of the radiation striking them at specific wavelengths. These substances are termed "black bodies." Theoretically, black bodies are perfect absorbers.

EMISSION—Emission refers to the radiation given off by a body. Every element in the atmosphere (gasses, clouds, and aerosols included) emits radiation. In general, atmospheric elements emit radiation at the same wavelength at which they absorb it. The energy radiated from a body's unit surface per unit time is known as the body's EMISSIVE POWER, while the ratio of emissive power of one body as compared to that of a black body under identical conditions (same wavelength and temperature) is known as EMISSIVITY.

Learning Objective: Identify the four factors affecting target detection.

TARGET DETECTION

Detection of a target at Earth's surface from aloft is a function of the following factors:

1. Target size
2. Distance from the target
3. Target- to background-energy contrast
4. The effects of the atmosphere on the transmission of energy from the target to the sensor

TARGET SIZE—Target size can range from relatively small to relatively large. An individual tank or a battery placement can be considered small, but so can a destroyer when compared to a weapons plant. Larger targets are, for the most part, easier to locate.

DISTANCE FROM THE TARGET—The farther away an aircraft is from a target, the smaller the target appears, and vice versa. Of course, the closer an aircraft gets to its target, the more susceptible the aircraft becomes to enemy fire.

TARGET- TO BACKGROUND-ENERGY CONTRAST—The physical processes that control target- to background-energy contrast are reflection, absorption, and emission.

Reflection is normally the most important process in locating a target or object for the visible and near-infrared wavelengths. Since the same intensity of sunlight falls on all surfaces, the amount of energy reflected by a target and the target's background determine whether enough contrast exists for a sensor to distinguish between the two. Without reflected sunlight or reflected energy from some artificial source, an object could not be detected unless it emitted significant amounts of visible or near-infrared radiation.

Reflection is also important at other infrared and microwave wavelengths. Visible and infrared lasers are used to spotlight targets for sensors that operate on the same wavelengths as the lasers. Similarly, at microwave wavelengths, radar returns from targets on the surface are reflected back to a microwave sensor.

Absorption by objects is dependent on the wavelength of the incident radiation. Electromagnetic energy that strikes a target or its background (incident radiation) and is not reflected is absorbed or transmitted.

Except for fires and other illuminators, such as searchlights, *emissions* of electromagnetic energy at visible wavelengths by targets and their backgrounds are practically zero in most cases. This is not to say that targets do not emit electromagnetic energy. Targets and backgrounds emit radiation at specific wavelengths dependent on the composition and physical temperature of the target and background.

The wavelengths of surface emissions are in the middle and far infrared ranges, and infrared sensors are used to measure these emissions.

EFFECTS OF THE ATMOSPHERE—The effects of the atmosphere on electromagnetic energy have already been discussed. Reduced visibilities due to the presence of clouds, precipitation, haze, smoke, fog, etc., all impact visual detection and the identification of targets.

Learning Objective: Name the various types of target acquisition systems, and identify the most proficient system.

TARGET ACQUISITION SYSTEMS

Target acquisition systems include the human eye, electrooptics (television sensors and display systems) radar, Forward Looking Infrared (FLIR) sensors, and laser seeker/tracker systems. Of these sensors, the human eye is the most capable of locating a target under most conditions. However, specific sensors can out-perform the human eye in some instances. For example, an electrooptical sensor adapted for low-light levels can out-perform the human eye at night under starlit skies, and a microwave system can out-perform the human eye because it can distinguish targets through clouds.

No matter what target acquisition system is used, the weapon must find its way to the target. This leads us into our next subject, which is Precision Guided Munitions (PGMs).

Learning Objective: Identify the two major components of precision guided munitions (PGMs).

PRECISION GUIDED MUNITIONS (PGMS)

After a target is located, PGMs are designed to accomplish two things: (1) to sense the difference between the electromagnetic radiation emitted or reflected by the target and that emitted or reflected by the target's surroundings, and (2) to guide the weapon to its target.

Two components make up the PGM; the guidance unit (seeker), and the control unit (tracker).

Guidance Unit

The guidance unit provides input to the control unit to guide or maneuver a PGM to a target. Electrooptical sensors are often used in these units and are most easily described as sophisticated television cameras. They can operate at visible wavelengths, infrared wavelengths, and at millimeter/microwave wavelengths. The sensor measures the reflected or emitted energy in its field of vision and converts it into electrical voltages. These voltages then drive electronic logic circuits that discriminate between the differences in a target's energy level and that of its surroundings. This ability to detect the contrast in energy levels is basic to any PGM's operation.

Two characteristics of guidance units are important from the viewpoint of environmental support: (1) each unit has a minimum energy contrast level. If this minimum level of energy contrast is not met, the logic circuits do not activate. The closer the target's temperature is to its surroundings, the more difficult it is for the unit to "lock on" the target. (2) guidance units can work only in limited energy ranges; too little energy cannot be detected, and too much energy saturates and can damage the sensor.

There are three types of guidance systems: active, semiactive, and passive.

ACTIVE.—With an active guidance system a PGM emits radiation in the direction of the target, and the target reflects the energy back to the PGM. The guidance unit senses the reflected radiation and "homes in" on the reflected energy beam. Active guidance systems respond to reflected energy.

SEMIACTIVE.—A semiactive guidance system is much the same as an active system except that the reflected energy that the unit "homes in" on originates from another aircraft or from a source on the ground.

PASSIVE.—Passive guidance systems home in on the naturally emitted or reflected energy contrast between a target and its background. In other words, passive systems distinguish thermal differences between the target and its surroundings.

Control Unit

The control unit activates the PGM's aerodynamic control surfaces to keep the pattern of energy differences within the field of view as it guides the PGM to its target. The term *lock-on* is used to describe the activation of the control unit. Once locked on, the PGM is guided toward the target. There are two fundamental sensor-tracker systems: the edge tracker and the centroid tracker.

EDGE TRACKER.—The edge tracker locks on the target and guides the PGM toward the area of most intense energy contrast within the sensor's field of view.

CENTROID TRACKER.—The centroid tracker is a dual-polarity system. It locks on the target and guides the PGM toward the center (centroid) of the most or least intense radiation (emitted or reflected) within the field of view. A polarity switch in the cockpit permits pilots to make the selection to lock on the maximum or minimum energy.

Learning Objective: Identify the advantages and disadvantages of PGMs.

ADVANTAGES AND DISADVANTAGES OF PGMs

The advantage of PGMs is improved accuracy in hitting an intended target. The disadvantages are weapon cost, sensitivity to the

environment, and aircraft exposure time to enemy defenses.

Weapons Cost

The cost of PGMs is extremely high compared to conventional munitions.

Environmental Sensitivity

PGMs are sensitive to weather and other environmental factors. There are no all-weather PGMs. The environment influences the effectiveness of PGMs in a highly complex manner. First, there are the effects of Earth's atmosphere and surface on the propagation of electromagnetic energy. Second, atmospheric elements such as turbulence, icing, hail, lightning, and electrical charge buildup (triboelectrification) all have the potential for adversely affecting the use of PGMs.

The degree of degradation caused by the above elements is not known in detail. However, severe turbulence or greater may be sufficient to break "lock-on." Icing can disturb the aerodynamic flight and coat the sensor cover so that it is no longer useful. Hail and large aerosols can render a sensor inoperative through ablation (deterioration through pitting of the sensor lens). Lightning and triboelectrification have the potential for creating transient currents in the PGM's electronics, which may affect system performance.

Table 6-4-1 lists the major atmospheric and solar effects on PGMs and TA systems. Figure 6-4-1 shows the effect of weather elements and sensor resolution on the various wavelength categories.

Exposure Time to Enemy Defenses

A major cause of concern in deciding whether to use PGMs is the time it takes for an aircraft to locate targets, obtain lock on, and launch. Because of all the factors involved in obtaining a successful PGM launch, exposure time to enemy defenses can be far more significant than with conventional munitions.

Table 6-4-1.—Major Atmospheric and Solar Effects on PGMs and TA Systems

PGM/TA SYSTEMS	ENVIRONMENTAL LIMITATIONS	TIME OF EMPLOYMENT	SYSTEM RESOLUTION
Eye/TV (Visible)	Clouds (includes fogs) Haze (includes all dry aerosols Sun angle Precipitation Light levels	Day (avoid dawn and dusk	High
Low Light Level TV (LLLTV) or Silicon Vidicon TV (Visible and near IR)	Clouds (includes fogs) Haze (includes all dry aerosols) Sun angle Precipitation Light levels	Day (and moonlight)	High
Laser (Infrared)	Clouds (other than very thin) Haze (Near IR only) Absolute humidity (Far and Far Far IR only)	Day or night	NOT APPLICABLE
Infrared	Clouds (other than very thin) Haze (Near IR only) Absolute humidity (Far and Far Far IR only)	Day or night	Medium
Millimeterwave/Microwave	Heavy clouds (high liquid water content) Precipitation	Day or night	Low

<table>
<tr><td rowspan="2">WAVELENGTH CATEGORIES</td><td rowspan="2">VISIBLE</td><td colspan="4">INFRARED</td><td rowspan="2">MILLIMETER</td><td rowspan="2">MICROWAVE</td></tr>
<tr><td>NEAR</td><td>MIDDLE</td><td>FAR</td><td>FAR FAR</td></tr>
<tr><td>WAVELENGTH/ FREQUENCIES</td><td>0.74μm-0.4μm</td><td>2μm-0.74μm</td><td>6μm-2μm</td><td>15μm-6μm</td><td>0.1mm-15μm</td><td>1cm-0.1mm</td><td>10cm-1cm
3GHz-30GHz</td></tr>
<tr><td>RESOLUTION</td><td colspan="7">USUALLY INCREASES WITH DECREASING WAVELENGTHS</td></tr>
<tr><td>WEATHER SENSITIVITY</td><td colspan="7">GENERALLY INCREASES WITH DECREASING WAVELENGTH</td></tr>
<tr><td>CLOUDS & FOGS</td><td colspan="4">EXTREMELY SIGNIFICANT</td><td colspan="3">SIGNIFICANT</td></tr>
<tr><td>DRY AEROSOLS</td><td colspan="2">EXTREMELY SIGNIFICANT</td><td colspan="2">SIGNIFICANT</td><td colspan="3">INSIGNIFICANT</td></tr>
<tr><td>PRECIPITATION</td><td colspan="5">EXTREMELY SIGNIFICANT</td><td colspan="2">SIGNIFICANT</td></tr>
<tr><td>ABSORPTION</td><td colspan="2">EXTREMELY SIGNIFICANT</td><td colspan="3">CAN BE EXTREMELY SIGNIFICANT</td><td colspan="2">SIGNIFICANT</td></tr>
<tr><td>SCATTERING</td><td colspan="4">EXTREMELY SIGNIFICANT</td><td colspan="3">SIGNIFICANT</td></tr>
</table>

Figure 6-4-1.—Significance of adverse weather and sensor resolution.

UNIT 6—LESSON 5

SOUND FOCUSING

OVERVIEW	OUTLINE
Identify the atmospheric elements that control blast waves in the atmosphere.	Blast waves
Identify the information and equipment necessary to manually compute sound focus, and identify the entries on the sound focus wind-speed component worksheet.	Computing sound focus
Identify sound-focus categories and sound-speed criteria.	Sound-focus categories and sound-speed criteria

SOUND FOCUSING

High speed flights of supersonic aircraft over communities bordering on major jet bases and ordnance explosions at near-shore target bombing ranges brought to light the problem of blast waves. Residents complained about broken windows, crockery, etc., from the blasts and began filing suits against the government to recoup their losses.

Because of the complaints, studies were conducted to evaluate noise levels under varying atmospheric conditions. From these studies, it was determined that certain atmospheric conditions add to the noise level of blasts, while other conditions lessen the noise level.

The predominant atmospheric conditions that add to the noise level of blasts are temperature increasing with height (inversions), wind speed increasing with height, and wind blowing toward an area of interest. In addition to the atmospheric conditions, the ordnance size, regional topography, and blast altitude also control the intensity of a blast wave.

As an Aerographer's Mate, you may be required to work up sound focusing data. Therefore, in this lesson, we will discuss the methods and techniques used in evaluating environmental elements that may increase or decrease the intensity of blast waves.

Learning Objective: Identify the atmospheric elements that control blast waves in the atmosphere.

BLAST WAVES

Blast waves are generated whenever explosives are detonated or when a jet breaks the sound barrier (a sonic boom). As an air blast moves past a given point, air pressure changes. First, the pressure rises rapidly to a value above the ambient (free air) pressure, then it decreases more slowly to a value below the ambient pressure. Finally, the pressure returns to the ambient value. This pressure change, like that created by a bolt of lightning, is rapid and produces sound. Sound waves accompany blast waves, and the laws of sound propagation discussed earlier apply to both blast and sound waves. The terms *blast waves* and *sound waves* are used synonymously in this lesson.

Direction of Blast Waves

To determine the path of a sound ray through the atmosphere, you need to know two things: (1) the initial direction of the ray when it leaves its source, and (2) the manner in which sound speed varies with altitude.

If sound speed is uniform throughout the air above ground level, sound rays move uniformly in all directions. If sound speed decreases from the surface upward, all sound rays are refracted upward, away from the surface. In this case, sound intensity along the surface decreases rapidly. If sound speed increases with altitude, sound rays are refracted downward, toward the surface. In this case, sound intensity increases at the surface.

Atmosphere Elements Affecting Velocity of Sound

Three atmospheric elements affect the velocity of sound traveling through the atmosphere: temperature, wind velocity (direction and speed), and relative humidity. Of these elements, temperature and wind have the greatest affect on sound speed. Relative humidity changes produce only minimal sound speed changes.

TEMPERATURE.—Temperature normally decreases with height through the atmosphere. This decrease in temperature causes sound waves to bend upward, away from the ground. This action is good with regard to blast waves, because blast noise is directed upward. On the other hand, when the temperature increases with height (an inversion) blast waves are bent downward, toward the ground, and property damage may result.

WIND VELOCITY.—Wind direction and speed can have a positive or a negative effect on blast waves. The wind may aid in pushing a blast wave in a direction where the noise level can produce damage, or it may retard the blast wave.

The positive or negative contribution of the wind is determined mathematically by comparing the true-wind direction to the vector (compass direction) between the blast point and the point of interest. The vector is the azimuth of interest. The blast wave travels along the azimuth of interest to reach the point of interest. The angle at which the true wind intersects an azimuth of interest determines whether the wind is having a positive, negative, or neutral affect on a blast wave.

Any component of the wind that assists in pushing the blast toward a point of interest is positive, while any component that deters a blast from reaching a point of interest is negative. A wind that blows perpendicular to the azimuth of interest neither aids nor retards a blast wave and is classified as neutral.

Figure 6-5-1, view A shows a vector of 290 degrees and the compass azimuth perpendicular to the azimuth of interest. A blast wave would travel along the 110-290 azimuth, or from the east-southeast to the west-northwest, toward the point of interest. View B shows the sectors and compass directions from which the wind must blow to aid or deter the blast wave from reaching the point of interest.

Wind and temperature information is usually obtained from the most recent radiosonde sounding taken in the proximity of the detonation or blast. For example, if bombing exercises are conducted at Bloodsworth Island, in the Chesapeake Bay, the closest radiosonde station is at Wallops Island, Virginia. Under most circumstances, the latest sounding from Wallops Island is used to compute sound focus for Bloodsworth Island bombing runs.

NOTE: Care must be exercised in choosing a sounding. The upper-air station closest to the bombing site may not always provide temperatures and winds representative of the bombing site. Topographical and synoptic weather pattern differences may preclude the use of the sounding from the closest station.

Learning Objective: Identify the information and equipment required to manually compute sound focus, and identify the entries on a sound focus wind-speed component worksheet.

COMPUTING SOUND FOCUS

To compute sound focus, you will need air temperatures and wind velocities at roughly 500-foot intervals up to an altitude of approximately 5,000 feet (850 millibars). This information is taken

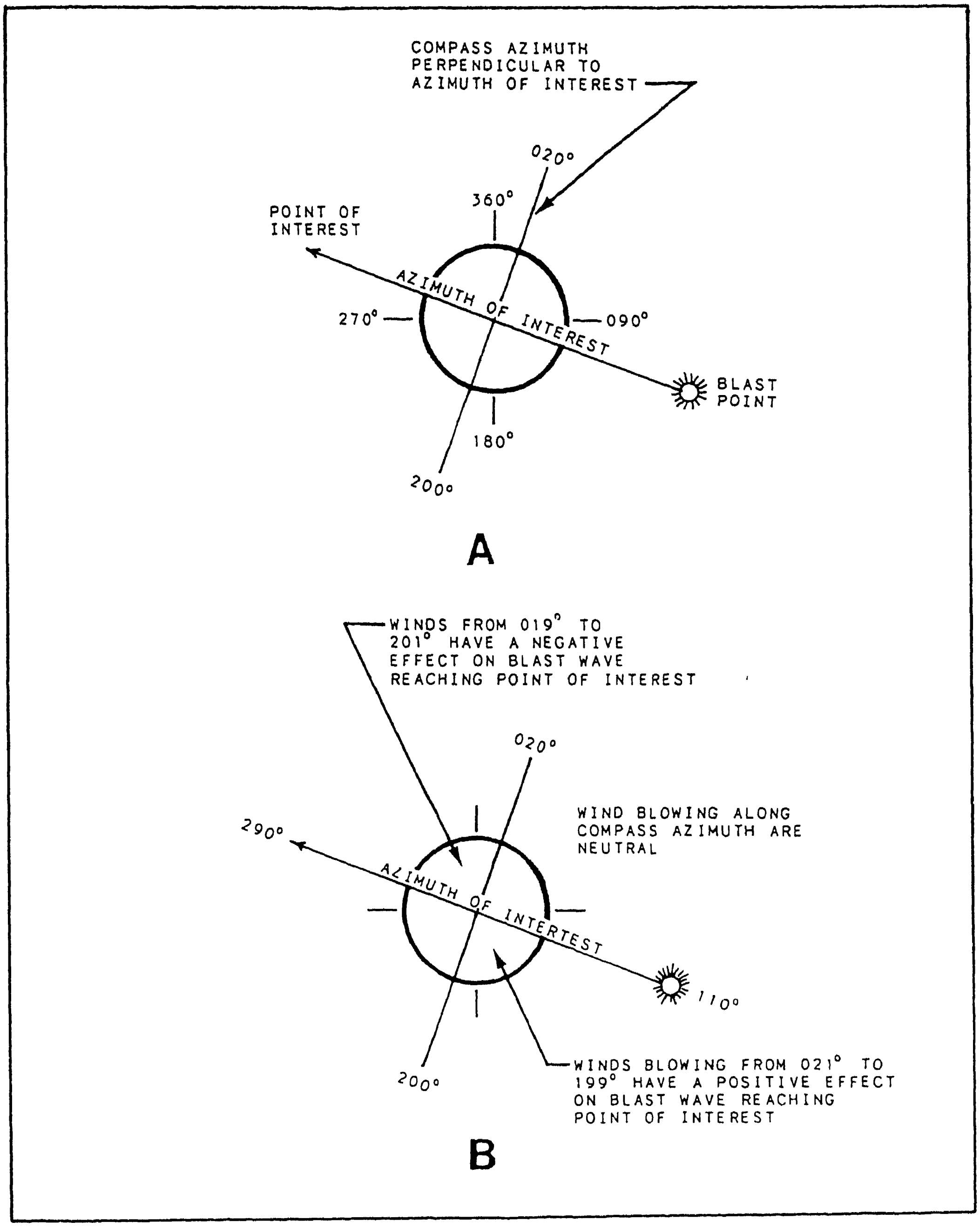


Figure 6-5-1.—Positive, negative, and neutral effect of winds along an azimuth of interest of 290°.

from an atmospheric sounding and placed on a sound focus wind-speed worksheet.

NOTE: Interpolation of pressure, temperature, wind direction, and speed may be necessary between the mandatory/significant levels.

In addition to the sounding and worksheet, two other items are necessary: a geographical map or chart of the area of interest, and an Atmospheric Speed Of Sound Calculator and Plotting Diagram.

Geographical Map

An aircraft navigational chart of the area of interest is ideal for the purpose of computing sound focus. The chart is used to locate the point

of detonation, and to determine distances and azimuths to areas or points of concern.

Sound Focus Wind-Speed Component Worksheet

An abbreviated version of a sound focus wind-speed worksheet is shown in figure 6-5-2. The information entered on the worksheet is as follows:

DATE/TIME—Enter the date and time of the sounding you are using.

POINT OF INTEREST—Enter the geographic location of the point of concern.

POINT OF BLAST—Enter the geographical location where the blast or detonation is going to take place.

AZIMUTH OF INTEREST—Enter the true bearing, in whole degrees, from the point of blast to the point of interest.

COLUMN (1), PPP—Enter the pressure at each selected level. Include all levels, mandatory and significant, up to and including the 850-mb level.

COLUMN (2), TTT—Enter the temperature at each selected level, in degrees and tenths.

COLUMN (3), DDD—Enter the true wind direction at each selected level.

COLUMN (4), FFF—Enter the wind speed at each selected level.

COLUMN (5), DDD MINUS (A1 + 180)—Use this formula to calculate the entry for column (5). A1 is the azimuth of interest. For example, if the true wind equals 150 degrees and the azimuth of interest is 160 degrees, using the formula DDD − (A1 + 180), we would find 150 − (160 + 180) or 150 − 340; finally reducing the entry for column (5) to − 190. The negative sign is important. It means the wind will retard the speed of sound.

COLUMN (6), COS(5)—Enter the cosine values for each of the column (5) entries. The worksheet contains the cosine values at 5-degree increments. See figure 6-5-2.

COLUMN (7), (4) × (6)—Multiply the entry in column 4 by the entry in column 6 for each level.

Three things can be determined from the information on the worksheet: (1) the sound-velocity gradient through the 5,000-foot layer, (2) whether or not a blast will occur, and (3) the blast wave intensity at a point of interest.

Atmospheric Speed Of Sound Calculator and Plotting Diagram

The Atmospheric Speed Of Sound Calculator and Plotting Diagram is used to compute the speed of sound. To use the diagram, you will need the pressure, height, and temperature information from your worksheet. Refer to figure 6-5-3 as we go over the use of the diagram.

Step 1. Take the temperature from the first line of the worksheet and locate this temperature on the temperature scale on the diagram. The temperature scale lies horizontally across the top of the diagram.

Step 2. Take the wind from the first line of the worksheet (column 7) and locate the wind on the wind-speed scale. The wind-speed scale lies horizontally across the bottom of the diagram.

Step 3. Using a straightedge, align the temperature, from step 1, with the wind speed, in step 2. Place a dot on the diagram at the pressure level taken from the first line of the worksheet (column 1).

Step 4. Using the pressure, temperature, and wind information from line 2 of the worksheet, repeat the first 3 steps. Continue this procedure until each line of the worksheet has been plotted.

Step 5. Connect the dots you have plotted on the diagram.

Learning Objective: Identify sound-focus categories and sound-speed criteria.

SOUND-FOCUS CATEGORIES AND SOUND-SPEED CRITERIA

The speed of sound diagram provides you with a vertical profile of the speed of sound with

SOUND FOCUS
WIND SPEED COMPONENT WORKSHEET

DATE/TIME ________________ Z

ᴾOINT OF INTEREST ________________________________

ᴾOINT OF BLAST ________________________________

ᴬZIMUTH OF INTEREST (A1) ________________________________

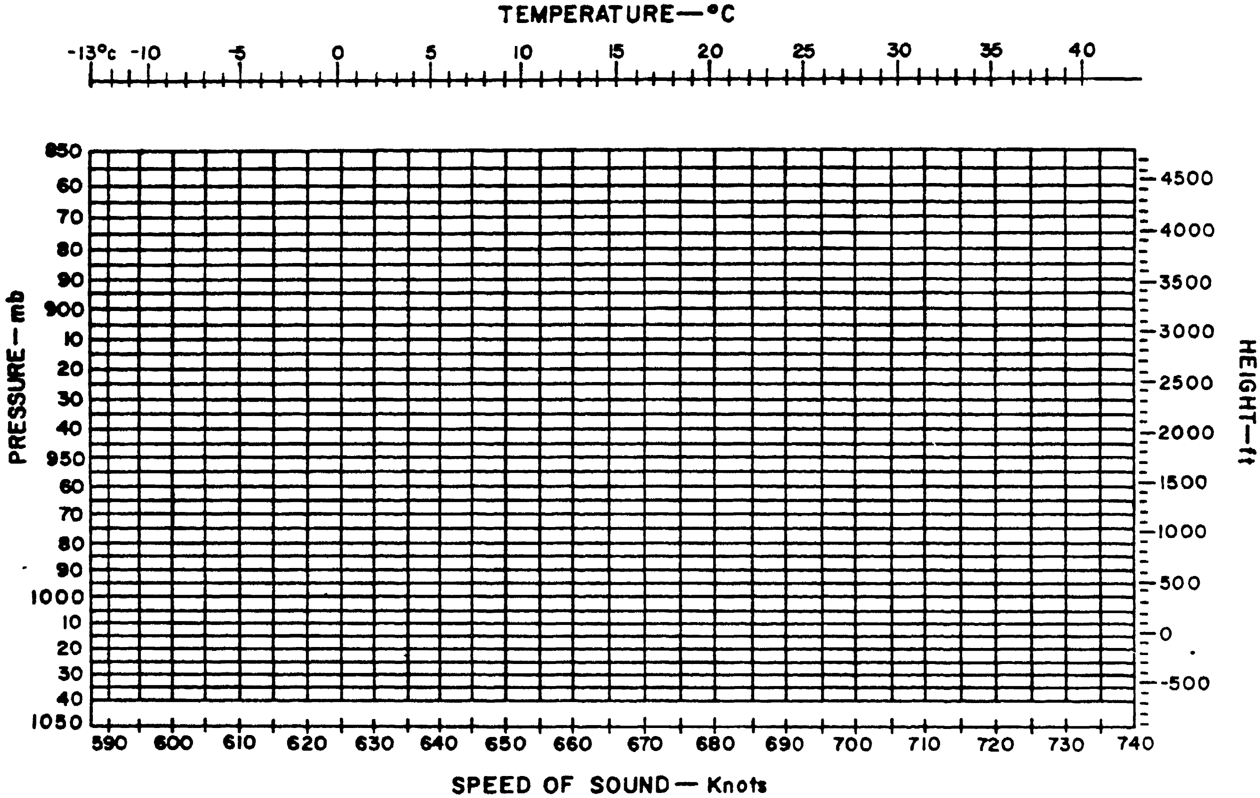
(1) PPP	(2) TTT	(3) DDD	(4) FFF	(5) /DDD Minus (A1 + 180)/	(6) COS(5)	(7) (4) × (6)

COSINE VALUES:

000°.	1.00	120°.	−.50	240°.	−.50
005°.	.99	125°.	−.57	245°.	−.42
010°.	.98	130°.	−.64	250°.	−.34
015°.	.96	135°.	−.71	255°.	−.26
020°.	.94	140°.	−.77	260°.	−.17
025°.	.91	145°.	−.82	265°.	−.09
030°.	.87	150°.	−.87	270°.	.00
035°.	.82	155°.	−.91	275°.	.09
040°.	.77	160°.	−.94	280°.	.17
045°.	.71	165°.	−.96	285°.	.26
050°.	.64	170°.	−.98	290°.	.34
055°.	.57	175°.	−.99	295°.	.42
060°.	.50	180°.	−1.00	300°.	.50
065°.	.42	185°.	−.99	305°.	.57
070°.	.34	190°.	−.98	310°.	.64
075°.	.26	195°.	−.96	315°.	.71
080°.	.17	200°.	−.94	320°.	.77
085°.	.09	205°.	−.91	325°.	.82
090°.	.00	210°.	−.87	330°.	.87
095°.	−.09	215°.	−.82	335°.	.91
100°.	−.17	220°.	−.77	340°.	.94
105°.	−.26	225°.	−.71	345°.	.96
110°.	−.34	230°.	−.64	350°.	.98
115°.	−.42	235°.	−.57	355°.	.99

Figure 6-5-2.—Sound focus wind-speed component worksheet.

ATMOSPHERIC SPEED OF SOUND CALCULATOR and PLOTTING DIAGRAM



INSTRUCTIONS

ALONG A STRAIGHT LINE JOINING TEMPERATURE AND WIND SPEED COMPONENT READ SPEED OF SOUND.

FOR PROBLEMS INVOLVING REFRACTION OF SOUND WAVES IN THE ATMOSPHERE, PLOT SPEED OF SOUND AGAINST PRESSURE ON THE DIAGRAM. IF SPEED OF SOUND INCREASES WITH INCREASING HEIGHT, RAYS WILL BEND TOWARD THE EARTH. IF THE SPEED OF SOUND AT ANY LEVEL ABOVE THE SURFACE EXCEEDS THE SPEED AT THE SURFACE, SOME SOUND ENERGY WHICH STARTED AWAY FROM THE SURFACE AT THE SOURCE WILL RETURN TO THE SURFACE.

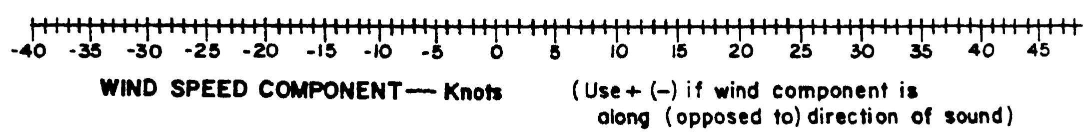


Figure 6-5-3.—Atmospheric Speed of Sound Calculator and Plotting Diagram.

height. The next step in computing sound focus is to compare the speed of sound at each level above the surface with the speed of sound at the surface. Remember, sound speed differences control whether sound waves will bend upward, downward, or travel in a straight line. The differences are then compared to sound focus sound-speed criteria to determine sound focus conditions. The criteria are as follows:

Sound-Focus Category	Criteria (Surface to 850-mb Level)
NIL	The speed of sound is constant or decreases with height.
SLIGHT	The speed of sound increases with height but does not exceed the speed of sound at the surface by more than 2 knots.
MODERATE	The speed of sound increases with height exceeding the speed of sound at the surface by 3 or 4 knots.
HEAVY	The speed of sound increases with height exceeding the speed of sound at the surface by 5 knots or more.

UNIT 6—LESSON 6

TIDES AND TIDAL COMPUTATIONS

OVERVIEW	OUTLINE
Recognize the effect of the Sun and the Moon on tides.	Factors affecting tides
Identify the four volumes of *Tide Tables*, and recognize how tides are computed.	Tide tables
Identify terms relating to tidal currents.	Tidal currents

TIDES AND TIDAL COMPUTATIONS

The tides are of primary importance to ship captains when preparing to get underway or enter port. Although Navy Quartermasters do the majority of tidal computations, many oceanography offices are tasked with computing and publishing tidal data for their local area.

Learning Objective: Recognize the effect of the Moon and the Sun on tides.

FACTORS AFFECTING TIDES

Gravitational attraction exists between Earth and the Moon and Earth and the Sun. It is an invisible force that acts to pull two bodies together. The strength, or magnitude, of the attraction is dependent on the mass of the two bodies and the distance between them.

Sir Isaac Newton deduced that gravitational attraction is (1) directly proportional to the product of the masses of two bodies and (2) inversely proportional to the square of the distance between them. In other words, the force of gravity increases if the product of the mass of the two bodies increases or if the distance between the two bodies decreases. Even though the Earth-Sun mass is much greater than the Earth-Moon mass, the gravitational attraction between Earth and the Moon is approximately 2 1/2 times greater than the Earth-Sun attraction. The reason for this is that the Moon is nearer Earth.

The Influence of the Moon and Sun on Tides

To a large extent, the height of the various tides depends on the Moon's position in relation to Earth. Refer to figure 6-6-1. On the side of

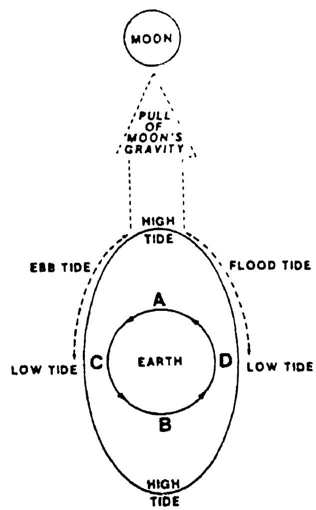


Figure 6-6-1.—Effect of the Moon's gravity.

Earth facing the Moon (A), gravity is greatest, because the side of Earth facing the Moon is closer to the Moon. The Moon's gravitational pull acts to pile water up on this side of Earth, producing the highest of the daily tides.

The Moon's gravitational attraction is weaker on the side of Earth facing away from the Moon (B), because that side is farther away from the Moon. High tides occur on this side of Earth as well, but they are not as high as those on the side facing the Moon.

On those parts of Earth that are not in line with the Moon (C and D), the water level of tides is lower than that occurring at A and B. The reason for the low tides over these regions is related to tractive forces. Tractive forces act tangentially to Earth's surface and cause the horizontal movement of water associated with tides—the tidal currents.

The Moon revolves around Earth once every 24 hours and 50 minutes, producing a daily tidal effect. In oceanography, this time period is referred to as a tidal day. When the Moon is new or full, the Sun and the Moon are aligned with Earth (fig. 6-6-2, view A). At these times, the gravitational pull on Earth is greater because of the combined gravitational attraction of the Sun and the Moon.

When the Moon is in its new and full phases, the high tides are higher than normal and the low tides are lower than normal. These tides are referred to as SPRING TIDES.

When the Moon is in its first- and third-quarter phases, the Sun and the Moon are at right angles to each other (fig. 6-6-2, view B). This alignment produces lower-than-normal high tides and higher-than-normal low tides. In other words, the range of the rise and fall of the water level is less than normal. These tides are referred to as NEAP TIDES.

Other Factors Affecting Tides

From the above information, it would appear that the rise and fall of the tides is pretty straightforward based on the position of the Moon and the Sun in relation to Earth. But this is not the case. The daily tides are not uniform.

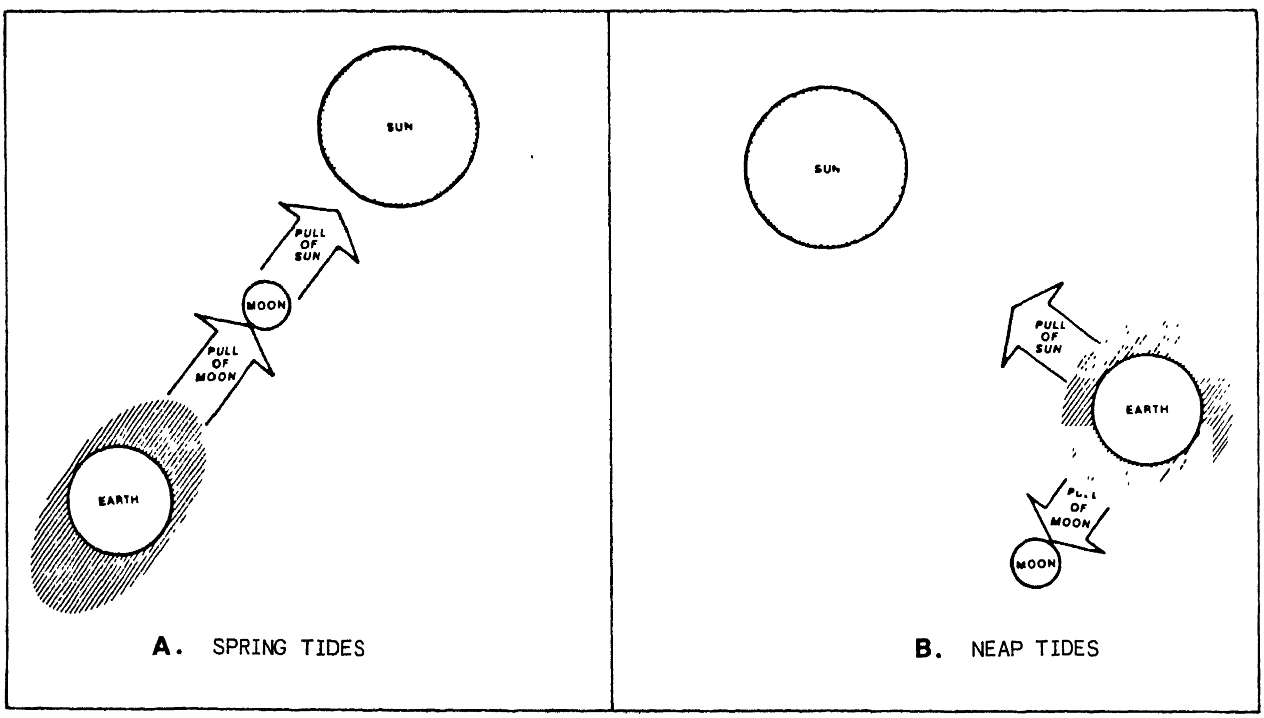


Figure 6-6-2.—Effect of the Moon and the Sun on neap tides.

Some places have two high and two low tides a day, while others may have one high and one low. Some places have tidal ranges well above 25 feet, while others have minimal ranges.

There are many variables in the processes that control the time and height of a tide at a particular maritime location. In addition to the relationship of the Moon, the Sun and Earth, Earth's coastline configurations, ocean bottom configurations, and the interaction of water (wave mechanics) all affect tides.

Mathematical models have been developed that will allow desk top computers to forecast tides based on the motions of the Moon, the Sun, and Earth. These programs are expected to be available for your use in the near future. The Tide Tables produced by the National Ocean Service computers must be used until then.

Learning Objective: Identify the four volumes of *Tide Tables* and recognize how the information is used to compute tides.

TIDE TABLES

Tide Tables is a four-volume set of books. Each volume contains tidal information on a specific geographical area of the world. Tide Tables is broken up geographically as follows:

- Volume 1—Europe and West Coast of Africa, including the Mediterranean Sea
- Volume 2—East Coast of North and South America, including Greenland
- Volume 3—West Coast of North and South America, including the Hawaiian Islands
- Volume 4—Central and Western Pacific Ocean and Indian Ocean

Within each volume there are seven tables: (1) Daily Tide Predictions, (2) Tidal Differences and Other Constants, (3) Height of Tide at Anytime, (4) Local Mean Time of Sunrise and Sunset, (5) Reduction of Local Mean Time to Standard Time, (6) Moonrise and Moonset, and (7) Conversion of Feet to Meters. Tide computations are primarily carried out using the first three tables.

Daily Tide Predictions

Listing the tides for every coastal location would result in volumes of tide tables so vast as to be economically infeasible. Therefore, daily tide predictions are provided for REFERENCE STATIONS only. Reference station tides are then used to calculate tides for other nearby stations known, as subordinate stations.

A copy of a page from Daily Tide Predictions is shown in figure 6-6-3. The reference station is listed at the top of the page, along with the year to which the information applies. Three months of tidal information is contained on each page. Under each month, the day, time, and height of high and low water are listed. The heights are listed in meters as well as in feet.

Another feature of Table 1 of *Tide Tables* is the "Typical Tide Curves." The tide curves show the day-to-day variations in the tide for various reference stations along a coast. Figure 6-6-4 is an example of typical tide curves. The days of the month are listed across the top of the page. The range of tide heights for each station listed is on the left. The names of the reference stations are centered above each set of curves. The phase of the Moon is pictured directly under the date on which the phase begins.

Tidal Differences and Other Constants

Table 2 of *Tide Tables*, Tidal Differences and Other Constants, provides the information required to calculate the tides for subordinate stations. Subordinate stations are arranged in geographical order and are numbered

CRESCENT CITY, CALIFORNIA, 1990

Times and Heights of High and Low Waters

OCTOBER

Day	Time (h m)	Height (ft)	Height (cm)
1 M	0257	0.6	18
	0927	6.2	189
	1517	2.0	61
	2109	6.4	195
2 Tu	0333	0.6	18
	0956	6.6	201
	1559	1.2	37
	2202	6.6	201
3 W	0410	0.8	24
	1022	7.1	216
	1641	0.5	15
	2250	6.7	204
4 Th	0443	1.1	34
	1054	7.5	229
	1723	-0.2	-6
	2339	6.6	201
5 F	0521	1.5	46
	1128	7.8	238
	1808	-0.8	-24
6 Sa	0032	6.5	198
	0600	1.9	58
	1205	8.0	244
	1856	-1.0	-30
7 Su	0126	6.2	189
	0642	2.4	73
	1244	8.0	244
	1946	-1.0	-30
8 M	0225	5.8	177
	0727	2.9	88
	1330	7.7	235
	2044	-0.8	-24
9 Tu	0331	5.5	168
	0823	3.3	101
	1423	7.4	226
	2147	-0.5	-15
10 W	0447	5.4	165
	0935	3.6	110
	1529	6.9	210
	2259	-0.1	-3
11 Th	0603	5.5	168
	1102	3.6	110
	1646	6.4	195
12 F	0007	0.1	3
	0710	5.7	174
	1230	3.3	101
	1813	6.2	189
13 Sa	0112	0.4	12
	0800	6.1	186
	1345	2.6	79
	1928	6.1	186
14 Su	0205	0.6	18
	0842	6.5	198
	1445	1.9	58
	2038	6.1	186
15 M	0253	0.9	27
	0917	6.8	207
	1533	1.3	40
	2133	6.2	189

Day	Time (h m)	Height (ft)	Height (cm)
16 Tu	0335	1.2	37
	0949	7.0	213
	1615	0.7	21
	2224	6.1	186
17 W	0410	1.6	49
	1019	7.2	219
	1654	0.2	6
	2309	6.1	186
18 Th	0442	2.0	61
	1045	7.2	219
	1729	-0.1	-3
	2352	6.0	183
19 F	0518	2.4	73
	1114	7.2	219
	1805	-0.2	-6
20 Sa	0034	5.8	177
	0546	2.8	85
	1142	7.1	216
	1840	-0.2	-6
21 Su	0119	5.7	174
	0621	3.2	98
	1210	6.9	210
	1918	-0.1	-3
22 M	0205	5.4	165
	0653	3.5	107
	1242	6.7	204
	1957	0.2	6
23 Tu	0254	5.2	158
	0732	3.7	113
	1317	6.4	195
	2044	0.4	12
24 W	0349	5.1	155
	0821	4.0	122
	1359	6.1	186
	2137	0.7	21
25 Th	0455	5.0	152
	0921	4.1	125
	1457	5.8	177
	2233	0.9	27
26 F	0554	5.2	158
	1045	4.0	122
	1607	5.5	168
	2333	1.0	30
27 Sa	0646	5.4	165
	1208	3.7	113
	1727	5.4	165
28 Su	0027	1.1	34
	0725	5.8	177
	1312	3.1	94
	1846	5.4	165
29 M	0115	1.2	37
	0757	6.2	189
	1409	2.2	67
	1955	5.6	171
30 Tu	0200	1.4	43
	0829	6.8	207
	1454	1.3	40
	2054	5.8	177
31 W	0244	1.6	49
	0903	7.3	223
	1536	0.3	9
	2151	6.1	186

NOVEMBER

Day	Time (h m)	Height (ft)	Height (cm)
1 Th	0326	1.8	55
	0935	7.8	238
	1622	-0.6	-18
	2245	6.3	192
2 F	0407	2.1	64
	1012	8.2	250
	1707	-1.3	-40
	2336	6.3	192
3 Sa	0449	2.4	73
	1051	8.4	256
	1753	-1.7	-52
4 Su	0032	6.3	192
	0534	2.8	85
	1133	8.5	259
	1842	-1.8	-55
5 M	0127	6.2	189
	0623	3.1	94
	1220	8.3	253
	1934	-1.6	-49
6 Tu	0223	6.1	186
	0715	3.3	101
	1310	7.9	241
	2028	-1.2	-37
7 W	0326	6.0	183
	0821	3.5	107
	1409	7.4	226
	2126	-0.7	-21
8 Th	0428	6.0	183
	0936	3.5	107
	1515	6.7	204
	2228	-0.1	-3
9 F	0530	6.1	186
	1102	3.3	101
	1634	6.1	186
	2331	0.5	15
10 Sa	0626	6.3	192
	1224	2.8	85
	1800	5.6	171
11 Su	0027	1.0	30
	0715	6.6	201
	1334	2.1	64
	1920	5.4	165
12 M	0122	1.5	46
	0757	6.9	210
	1433	1.4	43
	2032	5.4	165
13 Tu	0211	2.0	61
	0834	7.1	216
	1520	0.7	21
	2131	5.5	168
14 W	0253	2.4	73
	0906	7.3	223
	1600	0.2	6
	2226	5.6	171
15 Th	0335	2.8	85
	0935	7.4	226
	1638	-0.1	-3
	2311	5.7	174

Day	Time (h m)	Height (ft)	Height (cm)
16 F	0410	3.1	94
	1007	7.4	226
	1711	-0.4	-12
	2353	5.7	174
17 Sa	0445	3.3	101
	1036	7.3	223
	1746	-0.5	-15
18 Su	0032	5.7	174
	0521	3.5	107
	1108	7.2	219
	1821	-0.4	-12
19 M	0114	5.7	174
	0559	3.7	113
	1141	7.1	216
	1858	-0.3	-9
20 Tu	0153	5.6	171
	0635	3.8	116
	1216	6.9	210
	1937	-0.1	-3
21 W	0238	5.5	168
	0717	4.0	122
	1255	6.7	204
	2016	0.1	3
22 Th	0324	5.5	168
	0804	4.0	122
	1337	6.4	195
	2100	0.4	12
23 F	0409	5.6	171
	0907	4.0	122
	1422	6.0	183
	2142	0.7	21
24 Sa	0456	5.7	174
	1016	3.8	116
	1528	5.6	171
	2232	1.0	30
25 Su	0540	6.0	183
	1131	3.4	104
	1645	5.2	158
	2320	1.4	43
26 M	0619	6.4	195
	1241	2.6	79
	1810	5.0	152
27 Tu	0010	1.8	55
	0654	6.8	207
	1337	1.7	52
	1929	5.1	155
28 W	0101	2.2	67
	0733	7.3	223
	1429	0.7	21
	2043	5.3	162
29 Th	0153	2.5	76
	0813	7.8	238
	1517	-0.3	-9
	2146	5.6	171
30 F	0245	2.8	85
	0856	8.3	253
	1606	-1.1	-34
	2244	5.9	180

DECEMBER

Day	Time (h m)	Height (ft)	Height (cm)
1 Sa	0334	3.0	91
	0940	8.6	262
	1652	-1.7	-52
	2336	6.2	189
2 Su	0426	3.2	98
	1026	8.8	268
	1741	-2.0	-61
3 M	0027	6.3	192
	0519	3.3	101
	1117	8.8	268
	1829	-2.0	-61
4 Tu	0119	6.4	195
	0611	3.3	101
	1206	8.5	259
	1919	-1.8	-55
5 W	0211	6.4	195
	0709	3.3	101
	1258	8.0	244
	2009	-1.2	-37
6 Th	0300	6.5	198
	0815	3.3	101
	1357	7.4	226
	2100	-0.6	-18
7 F	0352	6.6	201
	0926	3.1	94
	1500	6.6	201
	2153	0.2	6
8 Sa	0446	6.7	204
	1043	2.9	88
	1613	5.8	177
	2241	1.0	30
9 Su	0536	6.9	210
	1202	2.4	73
	1735	5.2	158
	2337	1.7	52
10 M	0622	7.0	213
	1310	1.8	55
	1904	4.9	149
11 Tu	0029	2.4	73
	0706	7.1	216
	1410	1.2	37
	2025	4.9	149
12 W	0121	3.0	91
	0747	7.2	219
	1459	0.6	18
	2133	5.1	155
13 Th	0210	3.4	104
	0824	7.3	223
	1541	0.2	6
	2226	5.3	162
14 F	0302	3.7	113
	0901	7.3	223
	1620	-0.1	-3
	2312	5.5	168
15 Sa	0345	3.8	116
	0936	7.4	226
	1657	-0.3	-9
	2348	5.7	174

Day	Time (h m)
16 Su	0424
	1012
	1731
17 M	0029
	0503
	1050
	1806
18 Tu	0102
	0542
	1126
	1841
19 W	0134
	0621
	1201
	1917
20 Th	0209
	0703
	1239
	1949
21 F	0247
	0750
	1319
	2025
22 Sa	0320
	0845
	1407
	2100
23 Su	0355
	0944
	1503
	2139
24 M	0434
	1053
	1616
	2221
25 Tu	0512
	1202
	1741
	2309
26 W	0556
	1308
	1916
27 Th	0005
	0644
	1406
	2036
28 F	0111
	0735
	1502
	2147
29 Sa	0213
	0827
	1554
	2240
30 Su	0315
	0921
	1643
	2329
31 M	0415
	1013
	1729

Time meridian 120° W. 0000 is midnight. 1200 is noon.
Heights are referred to mean lower low water which is the chart datum of soundings.

Figure 6-6-3.—Sample of tidal prediction.

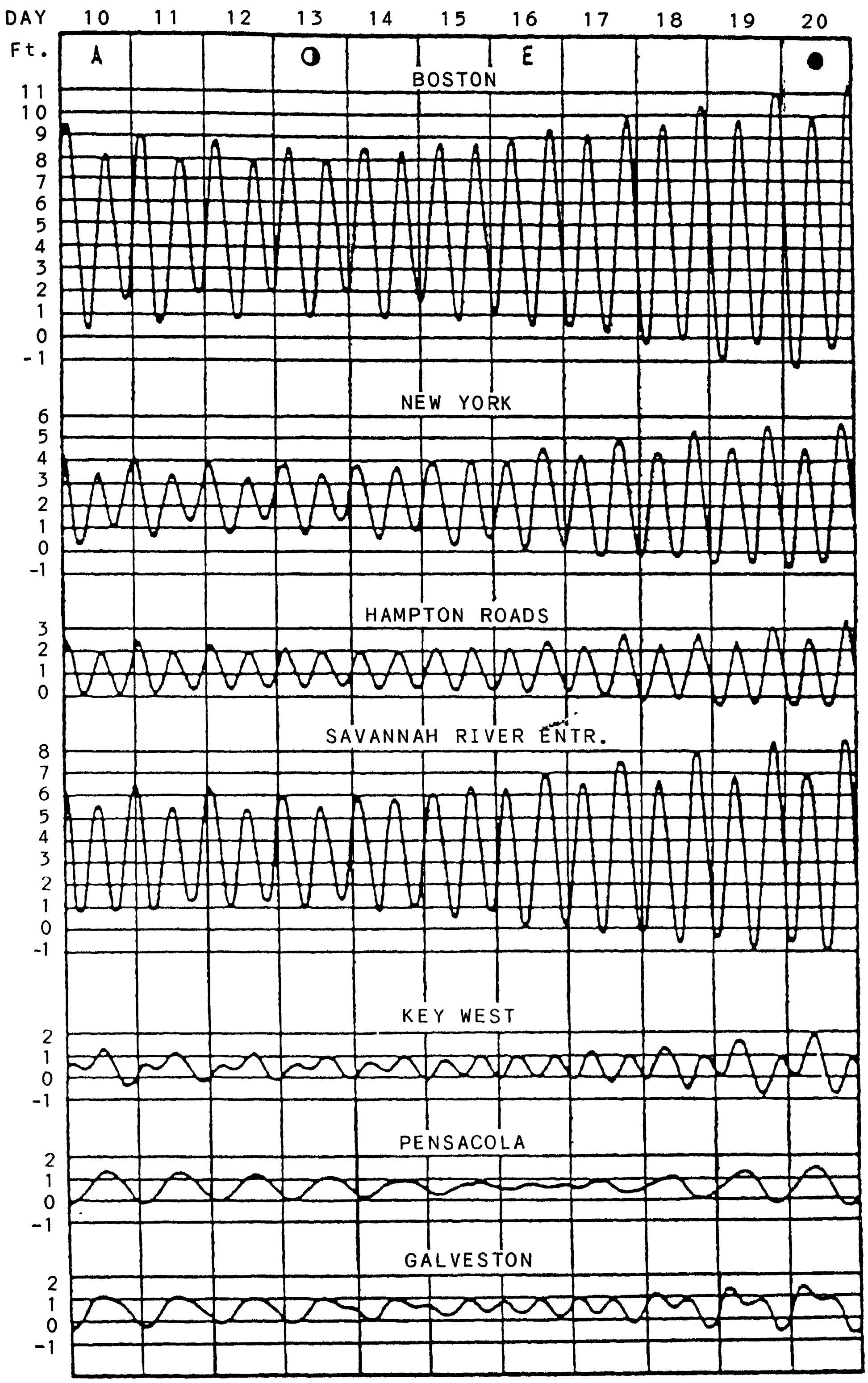


Figure 6-6-4.—Typical tidal curves.

NO.	PLACE	POSITION Lat.	Long.	DIFFERENCES Time High water	Low water	Height High water	Low water	RANGES Mean	Diurnal	Mean Tide Level
		° ' N	° ' W	h. m.	h. m.	ft	ft	ft	ft	ft
	San Joaquin River-Continued Time meridian, 120°W			on SAN FRANCISCO, p.72						
709	Blackslough Landing....................	38 00	121 25	+6 32	+7 21	*0.62	*0.36	2.7	3.6	1.8
711	Stockton................................	37 58	121 17	+6 37	+7 39	*0.68	*0.43	3.1	4.0	2.0
	Mokelumne River									
713	Georgiana Slough entrance...........	38 08	121 35	+6 05	+6 51	*0.54	*0.38	2.4	3.2	1.6
715	Terminous, South Fork...............	38 07	121 30	+6 25	+7 17	*0.58	*0.36	2.5	3.4	1.7
717	New Hope Bridge <4>................	38 14	121 29	+6 49	+7 58	*0.62	*0.45	2.7	3.6	1.8
719	Bishop Cut, Disappointment Slough.......	38 03	121 25	+6 43	+7 18	*0.66	*0.43	2.9	3.9	2.0
721	False River.............................	38 03	121 39	+5 16	+5 51	*0.55	*0.42	2.4	3.3	1.7
723	Irish Landing, Sand Mound Slough........	38 02	121 35	+5 56	+6 36	*0.62	*0.45	2.7	3.6	1.8
725	Orwood, Old River.......................	37 56	121 34	+6 59	+7 35	*0.63	*0.45	2.8	3.7	1.9
727	Holt, Whiskey Slough....................	37 56	121 26	+6 45	+7 41	*0.67	*0.45	3.0	3.9	2.0
728	Borden Highway Bridge, Old River........	37 53	121 34	+7 11	+7 41	*0.53	*0.40	2.3	3.2	1.6
729	Borden Highway Bridge, Middle River.....	37 54	121 29	+7 22	+7 59	*0.54	*0.37	2.4	3.2	1.6
731	Grant Line Canal (drawbridge)...........	37 49	121 27	+8 41	+9 22	*0.63	*0.45	2.8	3.7	1.9
	Sacramento River									
733	Collinsville............................	38 04	121 51	+3 43	+4 26	*0.65	*0.55	2.8	3.8	2.0
735	Threemile Slough........................	37 06	121 42	+4 20	+5 04	*0.69	*0.55	3.0	4.0	2.1
737	Rio Vista <4>...........................	38 09	121 42	+4 05	+5 13	*0.81	*0.55	3.6	4.7	2.4
739	Steamboat Slough, Snug Harbor Marina....	38 12	121 37	+4 55	+5 54	*0.67	*0.42	3.0	4.0	2.0
741	Snodgrass Slough........................	38 16	121 29	+7 31	+8 42	*0.40	*0.27	1.8	2.5	1.2
743	Clarksburg <4>..........................	38 25	121 31	+6 25	+8 04	*0.50	*0.27	2.3	2.9	1.4
745	Sacramento <4>..........................	38 35	121 30	+7 34	+9 34	*0.50	*0.27	2.3	2.9	1.4
	Outer Coast									
747	Bolinas Bay.............................	37 54	122 41	-0 25	-0 11	-0.1	0.0	4.0	5.7	3.1
749	Bolinas Lagoon..........................	37 55	122 41	-0 11	+0 37	-1.6	-0.4	3.0	4.3	2.2
751	Point Reyes.............................	38 00	122 58	-0 50	-0 26	-0.1	0.0	4.0	5.8	3.2
753	Tomales Bay entrance....................	38 14	122 59	-0 12	+0 20	*0.87	*0.91	3.5	5.2	2.7
755	Blakes Landing, Tomales Bay.............	38 11	122 55	+0 32	+1 15	-0.7	-0.2	3.6	5.2	2.7
757	Marshall, Tomales Bay...................	38 10	122 54	+0 38	+1 16	-0.6	-0.1	3.6	5.4	2.8
759	Inverness, Tomales Bay..................	38 06	122 51	+0 40	+1 24	-0.6	-0.2	3.7	5.3	2.8
761	Bodega Harbor entrance..................	38 18	123 03	-0 38	-0 16	-0.2	+0.1	3.8	5.7	3.1
763	Fort Ross...............................	38 31	123 15	-0 51	-0 30	-0.2	0.0	3.9	5.7	3.0
765	Arena Cove..............................	38 55	123 43	-0 40	-0 17	0.0	0.0	4.0	5.9	3.2
767	Point Arena.............................	38 57	123 44	-0 42	-0 21	-0.1	0.0	4.0	5.8	3.1
769	Albion..................................	39 14	123 46	-0 31	-0 19	-0.1	0.0	4.0	5.8	3.1
771	Little River Harbor.....................	39 16	123 47	-0 31	-0 19	-0.1	0.0	4.0	5.8	3.1
773	Mendocino, Mendocino Bay................	39 18	123 48	-0 38	-0 21	-0.1	0.0	4.0	5.8	3.1
775	Fort Bragg Landing......................	39 27	123 49	-0 30	-0 20	0.0	0.0	4.1	5.8	3.1
777	Noyo River..............................	39 25	123 48	-0 31	-0 12	+0.1	+0.1	4.1	6 0	3.2
779	Westport................................	39 38	123 47	-0 31	-0 22	-0.1	0.0	4.0	5.8	3.1
781	Shelter Cove............................	40 02	124 04	-0 39	-0 17	+0.2	+0.1	4.2	6.0	3.3
783	Cape Mendocino..........................	40 26	124 25	-0 28	+0 01	-0.1	0.0	4.0	5.7	3.1
				on CRESCENT CITY, p.80						
785	Eel River entrance......................	40 38	124 19	-0 05	-0 02	*0.89	*1.00	4.4	6.3	3.4
				on HUMBOLDT BAY, p.76						
	Humboldt Bay									
787	Entrance.............................	40 46	124 15	-0 09	+0 07	-0.7	0.0	4.3	6.2	3.3
789	HUMBOLDT BAY (North Spit)............	40 46	124 13	Daily predictions				5.0	6 9	3.7
791	Fields Landing.......................	40 43	124 13	-0 10	-0 02	-0.1	0.0	4.9	6.8	3.7
793	Hookton Slough.......................	40 41	124 13	+0 15	+0 25	-0.2	0.0	4.8	6.6	3.6
794	Elk River Railroad Bridge <18>......	40 45	124 12	+0 10	+1 26	-1.8	-0.9	4.0	5.1	2.4
795	Bucksport............................	40 47	124 12	+0 05	+0 02	+0.1	0.0	5.0	7.0	3.8
796	Eureka...............................	40 48	124 10	+0 17	+0 07	+0.4	0.0	5.3	7.3	3.9
797	Eureka Slough Bridge.................	40 48	124 08	+0 23	+0 06	+0.5	0.0	5.5	7.4	4.0
799	Samoa................................	40 50	124 11	+0 19	+0 07	+0.4	0.0	5.4	7.3	4.0
801	Arcata Wharf.........................	40 51	124 07	+0 48	+0 54	+0.1	+0.1	5.0	7.0	3.8
				on CRESCENT CITY, p.80						
803	Trinidad Harbor.............	41 03	124 09	+0 01	+0 01	*0.96	*0.98	4.9	6.7	3.6
805	CRESCENT CITY...........................	41 45	124 11	Daily predictions				5.1	7.0	3.8
	OREGON									
807	Brookings, Chetco Cove..................	42 03	124 17	+0 01	+0 04	*1.00	*1.00	5.1	6.9	3.7
809	Wedderburn, Rogue River.................	42 26	124 25	+0 09	+0 16	*0.95	*0.92	4.9	6.7	3.6
811	Port Orford.............................	42 44	124 30	+0 07	+0 09	*1.05	*1.08	5.3	7.3	3.9
813	Bandon, Coquille River..................	43 07	124 25	+0 23	+0 28	*1.00	*0.92	5.2	7.0	3.7
	Coos Bay									
815	Charleston...........................	43 21	124 19	+0 30	+0 30	*1.10	*1.00	5.7	7.5	4.1
817	Empire...............................	43 24	124 17	+1 12	+1 20	*0.95	*0.92	4.9	6.7	3.5
819	Coos Bay.............................	43 23	124 13	+2 01	+1 58	*1.06	*0.92	5.6	7.3	3.9
	Umpqua River									
821	Entrance.............................	43 41	124 12	+0 40	+0 33	*1.00	*1.00	5.1	6.9	3.7
823	Gardiner.............................	43 44	124 07	+1 31	+1 39	*0.97	*0.83	5.1	6.7	3.5
825	Reedsport............................	43 42	124 06	+1 46	+1 54	*0.97	*0.83	5.1	6.7	3.6

Endnotes can be found at the end of table 2.

Figure 6-6-5.—Sample of tidal differences and constants.

chronologically. See figure 6-6-5. Note that the table also provides the latitude and longitude of the subordinate stations, the time and the height differences of high and low water, the mean and spring tidal ranges, and the mean tide levels.

DIFFERENCES.—This section of the table contains the time and the height differences of high and low water between the subordinate station and the reference station. Where differences are omitted, they are unreliable or not known.

To obtain the times and heights of tides at a subordinate station on any date, you must apply the differences to the times and heights of the tides at the reference station for the same date.

Time Difference.—The time difference is the hours and minutes you apply to the reference station's time of high and low tide. The time difference is added to (+) or subtracted from (−) the reference station's time, depending on the sign preceding the time difference.

Height Difference.—The height differences in figure 6-6-5 are applied to the height of high and low water at the reference station. Height differences are usually given in feet. However, height differences may be given using ratios. Ratios may be shown for the high tide, low tide, or both. In this case, you must multiply the ratio by the tide height listed for the reference station to find the height of the tide(s) at the subordinate station. Height differences may also appear in the table (fig. 6-6-5) as a combination of a ratio and a height measurement. In this case, multiply the corresponding tide at the reference station by the ratio; then apply the height difference.

RANGE.—Two ranges are shown for subordinate stations. *Mean range* is the difference, in height, between the high tides and the low tides. *Spring range* is the annual average of the highest semidiurnal range, which occurs semimonthly (twice a month), when the Moon is in its new or full phase. The Spring tide range is larger than the mean range where the type of tide is either semidiurnal (two high tides and one low or two low and one high). The difference between the Spring tide range and the mean range is of no practical significance where the type of tide is diurnal (one high and one low tide a day). Where the tide is chiefly diurnal, the table gives the diurnal range, which is the difference in height between mean high water and mean low water.

NOTE: For stations where the tide is chiefly diurnal, time differences, height differences, and ratios are intended primarily for predicting the higher high and lower low waters. When the lower high water and higher low water at the reference station is nearly the same height, the corresponding tides often cannot be obtained satisfactorily by tidal differences.

MEAN TIDE LEVEL.—The mean tide level is the plane between mean low water and mean high water. Dashes are entered when the data is unreliable or unknown.

Computing Height of Tide

The approximate height of a tide at any time between its high and low water can be found by using "Table 3" of the *Tide Tables*, "Height of Tide at Any Time", or the height can be obtained graphically by using the Tidal Height Graph.

TABULAR METHOD.—Table 6-6-1, Height of Tide at Any Time, is used to compute a tide's height at any time between high tide and low tide. The table is made up of two sections: time and range.

Time.—Subtract the time of low water from the time of high water, or vice versa, to obtain the elapsed time (duration) between the two tides to the nearest hour (h) and minute (m). You will enter "Height of Tide at Any Time" with this time. Note that the duration times listed in the far-left column only cover durations between 4 hours (4 00) and 10 hours 40 minutes (10 40). When the duration is less than 4 hours or greater than 10 hours 40 minutes, you must adjust the duration time before using the table.

1. If the elapsed time is GREATER than 10 hours and 40 minutes, you must use one-half the duration period and then double the correction value.
2. If the elapsed time is LESS than 4 hours, you must double the duration period and then use one-half the correction value. When the tide is nearer high water, the correction value is subtracted. When the tide is nearer low water, the correction value is added.

Range.—To obtain the range of the tide, subtract the height of low water from the height of high water. You will enter the range section of "Height of Tide at Any Time" with this height difference if it is 20 feet or less. Note that the table's maximum range is 20 feet. When the range of the tide is greater than 20 feet, but less than

Table 6-6-1.—Height of Tide at Any Time

Duration of rise or fall, see footnote	Time from the nearest high water or low water														
h.m.	*h.m.*	*h.m.*	*h.m*	*h.m.*	*h.m.*	*h.m.*	*h.m.*	*h.m*	*h.m.*	*h.m.*	*h.m.*	*h.m.*	*h.m.*	*h.m.*	*h.m.*
4 00	0 08	0 16	0 24	0 32	0 40	0 48	0 56	1 04	1 12	1 20	1 28	1 36	1 44	1 52	2 00
4 20	0 09	0 17	0 26	0 35	0 43	0 52	1 01	1 09	1 18	1 27	1 35	1 44	1 53	2 01	2 10
4 40	0 09	0 19	0 28	0 37	0 47	0 56	1 05	1 15	1 24	1 33	1 43	1 52	2 01	2 11	2 20
5 00	0 10	0 20	0 30	0 40	0 50	1 00	1 10	1 20	1 30	1 40	1 50	2 00	2 10	2 20	2 30
5 20	0 11	0 21	0 32	0 43	0 53	1 04	1 15	1 25	1 36	1 47	1 57	2 08	2 19	2 29	2 40
5 40	0 11	0 23	0 34	0 45	0 57	1 08	1 19	1 31	1 42	1 53	2 05	2 16	2 27	2 39	2 50
6 00	0 12	0 24	0 36	0 48	1 00	1 12	1 24	1 36	1 48	2 00	2 12	2 24	2 36	2 48	3 00
6 20	0 13	0 25	0 38	0 51	1 03	1 16	1 29	1 41	1 54	2 07	2 19	2 32	2 45	2 57	3 10
6 40	0 13	0 27	0 40	0 53	1 07	1 20	1 33	1 47	2 00	2 13	2 27	2 40	2 53	3 07	3 20
7 00	0 14	0 28	0 42	0 56	1 10	1 24	1 38	1 52	2 06	2 20	2 34	2 48	3 02	3 16	3 30
7 20	0 15	0 29	0 44	0 59	1 13	1 28	1 43	1 57	2 12	2 27	2 41	2 56	3 11	3 25	3 40
7 40	0 15	0 31	0 46	1 01	1 17	1 32	1 47	2 03	2 18	2 33	2 49	3 04	3 19	3 35	3 50
8 00	0 16	0 32	0 48	1 04	1 20	1 36	1 52	2 08	2 24	2 40	2 56	3 12	3 28	3 44	4 00
8 20	0 17	0 33	0 50	1 07	1 23	1 40	1 57	2 13	2 30	2 47	3 03	3 20	3 37	3 53	4 10
8 40	0 17	0 35	0 52	1 09	1 27	1 44	2 01	2 19	2 36	2 53	3 11	3 28	3 45	4 03	4 20
9 00	0 18	0 36	0 54	1 12	1 30	1 48	2 06	2 24	2 42	3 00	3 18	3 36	3 54	4 12	4 30
9 20	0 19	0 37	0 56	1 15	1 33	1 52	2 11	2 29	2 48	3 07	3 25	3 44	4 03	4 21	4 40
9 40	0 19	0 39	0 58	1 17	1 37	1 56	2 15	2 35	2 54	3 13	3 33	3 52	4 11	4 31	4 50
10 00	0 20	0 40	1 00	1 20	1 40	2 00	2 20	2 40	3 00	3 20	3 40	4 00	4 20	4 40	5 00
10 20	0 21	0 41	1 02	1 23	1 43	2 04	2 25	2 45	3 06	3 27	3 47	4 08	4 29	4 49	5 10
10 40	0 21	0 43	1 04	1 25	1 47	2 08	2 29	2 51	3 12	3 33	3 55	4 16	4 37	4 59	5 20

Range of tide, see footnote	Correction to height														
Ft.	*Ft*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft*	*Ft.*	*Ft.*	*Ft.*	*Ft*	*Ft.*	*Ft.*	*Ft.*	*Ft*	*Ft*
0.5	0 0	0 0	0.0	0.0	0 0	0 0	0.1	0.1	0 1	0.1	0.1	0 2	0.2	0 2	0.2
1.0	0.0	0 0	0.0	0.0	0.1	0.1	0 1	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.5
1.5	0.0	0.0	0 0	0.1	0.1	0 1	0.2	0 2	0.3	0 4	0.4	0.5	0.6	0 7	0 8
2.0	0 0	0 0	0.0	0 1	0 1	0.2	0 3	0.3	0.4	0.5	0.6	0 7	0.8	0 9	1 0
2.5	0.0	0 0	0 1	0 1	0 2	0.2	0 3	0.4	0.5	0 6	0.7	0.9	1.0	1 1	1 2
3.0	0 0	0.0	0.1	0 1	0 2	0 3	0 4	0 5	0.6	0.8	0.9	1.0	1.2	1 3	1 5
3.5	0.0	0.0	0 1	0.2	0 2	0 3	0 4	0 6	0 7	0 9	1 0	1 2	1 4	1 6	1 8
4.0	0 0	0 0	0.1	0 2	0 3	0 4	0.5	0 7	0 8	1 0	1 2	1.4	1.6	1 8	2.0
4.5	0 0	0 0	0 1	0 2	0 3	0.4	0.6	0 7	0.9	1 1	1 3	1 6	1 8	2 0	2 2
5.0	0 0	0.1	0 1	0 2	0 3	0 5	0 6	0 8	1 0	1 2	1 5	1 7	2 0	2 2	2 5
5.5	0 0	0 1	0 1	0 2	0 4	0.5	0 7	0 9	1 1	1 4	1 6	1 9	2 2	2 5	2 8
6.0	0.0	0 1	0 1	0.3	0.4	0 6	0 8	1 0	1 2	1 5	1 8	2 1	2.4	2 7	3 0
6.5	0.0	0 1	0 2	0.3	0 4	0 6	0.8	1 1	1 3	1 6	1 9	2 2	2 6	2 9	3 2
7.0	0 0	0 1	0 2	0 3	0 5	0 7	0.9	1 2	1 4	1 8	2 1	2 4	2 8	3 1	3 5
7.5	0 0	0 1	0 2	0 3	0 5	0 7	1 0	1 2	1.5	1 9	2 2	2 6	3 0	3 4	3 8
8.0	0 0	0 1	0 2	0 3	0 5	0 8	1 0	1 3	1 6	2 0	2 4	2 8	3 2	3 6	4 0
8.5	0 0	0 1	0 2	0 4	0 6	0 8	1.1	1 4	1 8	2 1	2 5	2 9	3 4	3 8	4 2
9.0	0 0	0 1	0 2	0 4	0 6	0 9	1 2	1 5	1 9	2 2	2 7	3 1	3 6	4 0	4 5
9.5	0 0	0 1	0 2	0 4	0 6	0 9	1 2	1 6	2 0	2 4	2 8	3 3	3 8	4 3	4 8
10.0	0.0	0 1	0 2	0 4	0 7	1 0	1 3	1 7	2 1	2 5	3 0	3 5	4 0	4 5	5 0
10.5	0 0	0 1	0 3	0 5	0 7	1 0	1 3	1 7	2 2	2 6	3.1	3 6	4 2	4 7	5 2
11.0	0.0	0 1	0 3	0.5	0 7	1 1	1 4	1 8	2 3	2 8	3 3	3 8	4 4	4 9	5 5
11.5	0 0	0 1	0 3	0.5	0 8	1 1	1 5	1 9	2 4	2 9	3 4	4 0	4 6	5 1	5 8
12.0	0 0	0.1	0 3	0 5	0 8	1 1	1 5	2 0	2 5	3 0	3 6	4 1	4 8	5 4	6 0
12.5	0.0	0 1	0 3	0 5	0 8	1 2	1 6	2 1	2 6	3 1	3 7	4 3	5 0	5 6	6 2
13.0	0 0	0 1	0 3	0 6	0 9	1 2	1 7	2 2	2 7	3 2	3 9	4 5	5 1	5 8	6 5
13.5	0.0	0 1	0 3	0 6	0 9	1.3	1 7	2 2	2 8	3 4	4.0	4 7	5 3	6 0	6.8
14.0	0 0	0 2	0 3	0 6	0 9	1 3	1 8	2 3	2 9	3 5	4 2	4 8	5 5	6 3	7 0
14.5	0 0	0 2	0 4	0 6	1 0	1 4	1 9	2 4	3 0	3 6	4.3	5 0	5 7	6 5	7 2
15.0	0 0	0 2	0 4	0 6	1 0	1 4	1.9	2 5	3 1	3 8	4 4	5 2	5 9	6.7	7 5
15.5	0.0	0.2	0.4	0.7	1 0	1 5	2 0	2 6	3 2	3 9	4 6	5 4	6 1	6.9	7 8
16.0	0.0	0 2	0 4	0.7	1.1	1.5	2 1	2 6	3 3	4 0	4 7	5.5	6 3	7.2	8 0
16.5	0.0	0 2	0.4	0 7	1 1	1.6	2 1	2.7	3 4	4 1	4.9	5.7	6.5	7 4	8.2
17.0	0.0	0.2	0 4	0 7	1 1	1.6	2 2	2.8	3 5	4 2	5.0	5.9	6.7	7 6	8.5
17.5	0.0	0.2	0 4	0.8	1.2	1 7	2 2	2 9	3.6	4.4	5 2	6 0	6.9	7 8	8 8
18.0	0.0	0.2	0.4	0 8	1 2	1.7	2 3	3.0	3 7	4 5	5 3	6.2	7.1	8.1	9.0
18.5	0.1	0.2	0 5	0 8	1.2	1 8	2.4	3.1	3 8	4 6	5.5	6.4	7.3	8 3	9.2
19.0	0.1	0.2	0 5	0 8	1.3	1 8	2.4	3 1	3 9	4.8	5.6	6.6	7 5	8.5	9.5
19.5	0.1	0 2	0.5	0 8	1.3	1 9	2.5	3.2	4 0	4 9	5 8	6 7	7.7	8 7	9.8
20.0	0.1	0 2	0.5	0 9	1 3	1.9	2.6	3.3	4.1	5 0	5 9	6.9	7.9	9.0	10 0

40 feet, you must halve the range before using the table, then double the correction value. When the range is greater than 40 feet, enter the table using one-third of the range, then multiply the correction by 3. The same rule applies to the height correction value as it does for time: the correction is subtracted when the tide is nearer high water, and added when nearer low water.

GRAPHICAL METHOD.—The graphical method is used if the height of a tide is needed for different times during a day. This method assumes that the rise and fall of tides conforms to a simple "cosine" curve. If the tide follows a cosine curve, the graph can provide an accurate estimate of tide heights between high and low water; however, if the tide does not follow the cosine curve, the tide estimates will be off. To determine tides using the graphical method, use the following example:

<u>EXAMPLE</u>: High tide occurs at 0012 and is 11.3 feet; low tide occurs at 0638 and is −2.0 feet

1. Using graph paper, set up a time scale and a height scale. See figure 6-6-6.
2. Plot the time and height of high water and low water, and connect the two points with a straight line. See figure 6-6-7.
3. Divide the line into quarters as shown in figure 6-6-8.
4. At the quarter point closest to the high-water point, draw a vertical line equal to one-tenth of the tide's range. In our example, the range is 13 feet; 1/10 of 13 is equal to 1.3 feet. Because this point is nearer the high tide, draw this line up, toward the top of the graph (B′ in figure 6-6-9). Repeat this procedure for the

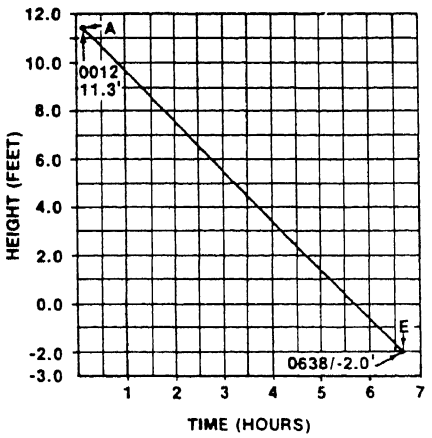


Figure 6-6-6.—Time and height scales.

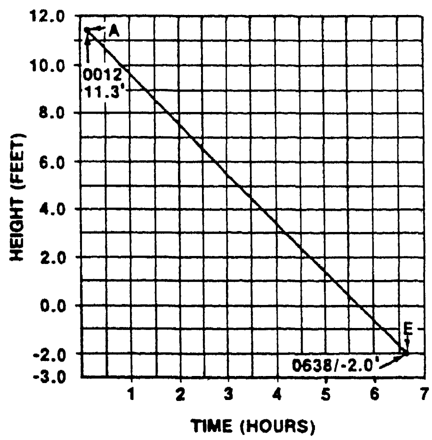


Figure 6-6-7.—High tide and low tide plotted on a graph.

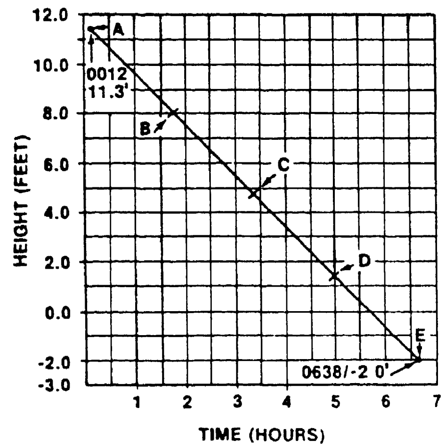


Figure 6-6-8.—Divided tide line.

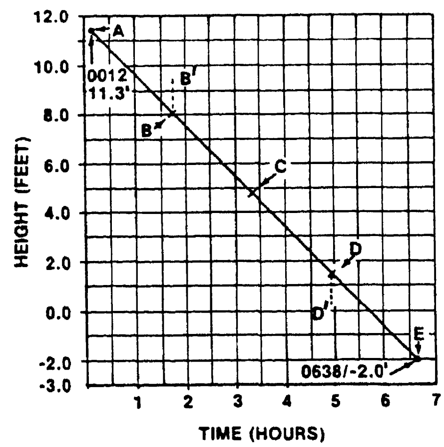


Figure 6-6-9.—One-tenth of the range is plotted.

quarter point closest to the low-water point but draw the line toward the bottom of the graph (D′ in figure 6-6-9).

5. Draw a smooth cosine curve connecting points A, B′, C, D′, and E, as shown in figure 6-6-10.

The graph is now complete and ready to use. To find the height of the tide at any time, simply follow the time upward until you intersect the cosine curve. From this point move horizontally to the height scale on the left and read the height.

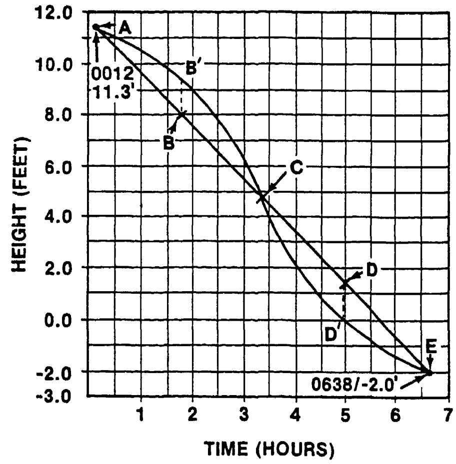


Figure 6-6-10.—Completed graph for tidal height.

Learning Objective: Identify the terms relating to tidal currents.

TIDAL CURRENTS

Tides rise and fall because of the water's movement due to gravity. As a tide rises, water moves toward shore. A rising tide, or incoming tide, is known as a flood tide. As a tide falls, water flows seaward. A falling, or outgoing, tide is known as an ebb tide. When the tide floods and ebbs, the movement of water shoreward or seaward can be significant or hardly noticeable. The horizontal movement of water caused by tide changes is often referred to as the tidal current. In estuaries, the tidal currents are often quite fast, exceeding 5 knots; in the open ocean, tidal currents rarely exceed 1 knot.

There is a period of time between an ebb tide and a flood tide when there is no appreciable horizontal movement of water. This period is known as "slack water."

There is another period of time between an ebb tide and a flood tide when there is no appreciable vertical movement of water. This period is known as a "stand."

It would appear that the "slack water" period and the "stand" period should coincide, but this is not always the case. Along a regular coastline, the two periods should coincide. But where a larger bay connects with an ocean through a narrow channel, the tide may continue to "flood" in the channel long after the high water stand, and vice versa. In other words, the tidal current continues in the channel after the water has stopped rising or falling.

For stations well exposed to the ocean there is usually little difference between the time of high and low water and the beginning of the flood or ebb tide. However, in narrow channels, landlocked harbors, or on tidal rivers, the time of slack water may differ by 2 or 3 hours from the time of high- or low-water *stand*.

UNIT 6—LESSON 7

COMPUTING SUNRISE AND SUNSET

OVERVIEW	OUTLINE
Identify the source used to compute times of sunrise and sunset.	Air Almanac
Compute times of sunrise and sunset using the Sunrise and Sunset tables.	Sunrise and sunset computations
Identify the procedures used to convert Local Mean Time to Local Standard Time and Universal Time Coordinated.	Converting time
Define twilight, and identify the tables and procedures used in twilight computations.	Morning and evening twilight
Identify the table, graphs, and procedures used to compute sunrise, sunset, and twilight for locations north of 72° N.	Sunlight and Twilight Tables

COMPUTING SUNRISE AND SUNSET

The positional relationship of the Sun and Earth is critical to the climatic controls influencing Earth's environment. Because of Earth's elliptical orbit around the Sun, the amount of sunlight varies with latitude. As we have already discussed in *AG2* - Volume 1, some regions of Earth spend 6 months of the year in darkness, while other regions get more sunlight than darkness and vice versa.

The Earth-Sun relationship can also play an important part in naval operations. The length of daylight versus darkness, or the time of sunrise and sunset can be critical to many peacetime, as well as wartime, operations.

Aerographer's Mates are usually tasked with computing the times of sunrise and sunset for their own stations. Usually, the times are computed months in advance, and the daily information is published in the plan of the day and/or the daily weather bulletin.

Learning Objective: Identify the source used to compute sunrise and sunset.

AIR ALMANAC

A copy of *Air Almanac* is found in most weather offices. It contains tables and figures for computing times of sunrise, sunset, and morning and evening civil twilight. *Air Almanac* is published yearly.

Table 6-7-1 is a sample of the Sunrise and Sunset tables as taken from the 1989 edition of *Air Almanac*. The top table is for sunrise computations, while the lower table is used to compute sunset.

The tables are formulated in the same manner. Latitudes between 72 °N and 60 °S are listed vertically on the left in various increments. Two-degree increments are used between 72 °N and 50 °N; five-degree increments are used between 50 °N and 30 °N, etc. The months and dates are listed horizontally across the top of each table in 3-day increments.

The Sunlight and Twilight table, which I will discuss further later, is used to compute sunrise and sunset for latitudes north of 72 °N. *Air Almanac* does not contain sunrise, sunset, or twilight information for latitudes south of 60 °S.

The times of sunrise and sunset are listed in hours (h) and minutes (m) for each latitude and date listed. When the Sun is continuously above or below the horizon, symbols are used in place of the hours and minutes. The symbol is printed for those latitudes and dates when the Sun is continuously above the horizon, and is used when the Sun is continuously below the horizon. The times are in Local Mean Time (LMT) and must be converted to Local Standard Time (LST) or Universal Time Coordinated (UTC). I will cover the time conversion later in this lesson.

Learning Objective: Compute times of sunrise and sunset.

SUNRISE AND SUNSET COMPUTATIONS

How you determine sunrise and sunset depends on the latitude and date(s) with which you enter the tables. If the date and latitude are listed, you simply find where the two intersect and read the time. However, if you enter the table with a latitude and/or date that falls between the latitudes and dates listed, you must interpolate the time.

For a quick walk through, let's use table 6-7-1 and go through a few examples, as follows:

EXAMPLE 1: Find the time of sunrise at 35 °N on 10 July. First, find 35 °N along the left edge of the table. Next, read across, horizontally, until you intersect the time beneath 10 July. If your answer is something other than 04:54, you have misused the table.

EXAMPLE 2: Determine sunrise on 10 July at 37 °N. Note that latitude 37 °N is not listed in the list of latitudes. Since 37 °N is not listed, the time of sunrise along 37 °N is not listed. The time of sunrise has to be interpolated. To interpolate the time of sunrise for 37 °N, use the sunrise times for the latitudes listed on each side of 37 °N. That is, find the time of sunrise for 35 °N and 40 °N.

Since we have already computed the time of sunrise for 35 °N on 10 July as 04:54, you have only to determine the time of sunrise for 40 °N. You should come up with a time of 04:40. Now, it is simply a matter of interpolating the time of sunrise. Using the sunrise times for 35 °N and 40 °N, set up the information as follows:

LATITUDE TIME

40 °N = 04:40

5 37 °N = X 14

2 X

35 °N = 04:54

The difference in the time of sunrise between 35 °N and 40 °N is 14 minutes, and the difference in degrees of latitude between 35 °N and 40 °N is 5 degrees. Since 37 °N is between 35 °N and 40 °N, the time of sunrise at 37 °N must occur between 04:40 and 04:54. To find the time of sunrise at 37 °N, set up a ratio of degrees-to-minutes using the differences in degrees, 2° and 5°, and the differences in time, 14 minutes and X.

The 5 degrees of latitude between 35 °N and 40 °N is equal to 14 minutes (04:54 − 04:40 = 14 minutes). To find the time that equals 2 degrees, use the ratio *5 degrees is to 14 minutes as 2 degrees is to X* (the unknown amount of minutes); then cross multiply.

$$\frac{5}{14} = \frac{2}{X}$$

$$5X = 28$$

$$X = 5.6 \text{ minutes (6 rounded off)}$$

Table 6-7-1.—Sample Page of Sunrise/Sunset Data

SUNRISE

Lat.	June	July											August				
	28	1	4	7	10	13	16	19	22	25	28	31	3	6	9	12	15
°	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
N 72	▭	▭	▭	▭	▭	▭	▭	▭	▭	▭	▭	▭	▭	00 49	01 30	01 58	02 21
70	▭	▭	▭	▭	▭	▭	▭	▭	▭	▭	00 21	01 11	01 39	02 01	02 20	02 37	02 54
68	▭	▭	▭	▭	▭	▭	▭	00 39	01 10	01 32	01 50	02 07	02 22	02 37	02 51	03 04	03 17
66	▭	00 13	00 38	00 55	01 10	01 24	01 37	01 50	02 03	02 15	02 27	02 39	02 51	03 03	03 14	25	36
64	01 35	01 40	01 46	01 52	02 00	02 08	02 17	02 26	35	02 44	02 54	03 03	03 13	22	32	41	03 50
62	02 13	02 16	02 20	02 25	31	37	02 44	02 51	02 58	03 06	03 14	22	30	38	46	03 54	04 02
N 60	02 39	02 42	02 45	02 49	02 54	02 59	03 04	03 10	03 17	03 23	03 30	03 37	03 44	03 51	03 58	04 06	04 13
58	02 59	03 01	03 04	03 08	03 12	03 16	21	26	32	38	44	03 50	03 56	04 02	04 09	15	22
56	03 16	18	20	23	27	31	35	40	45	03 50	03 55	04 01	04 06	12	18	24	30
54	30	32	34	37	40	44	48	03 52	03 56	04 01	04 06	11	16	21	26	31	37
52	42	44	46	49	03 52	03 55	03 58	04 02	04 06	10	15	19	24	29	33	38	43
N 50	03 53	03 54	03 57	03 59	04 02	04 05	04 08	04 11	04 15	04 19	04 23	04 27	04 31	04 35	04 40	04 44	04 49
45	04 15	04 17	04 18	04 20	23	25	28	31	34	37	40	43	47	04 50	04 54	04 57	05 01
40	33	34	36	38	40	42	44	46	04 49	04 51	04 54	04 57	04 59	05 02	05 05	05 08	11
35	04 48	04 49	04 51	04 52	04 54	04 56	04 57	04 59	05 01	05 04	05 06	05 08	05 10	13	15	17	19
30	05 01	05 02	05 03	05 05	05 06	05 08	05 09	05 11	13	14	16	18	20	22	23	25	27
N 20	05 23	05 24	05 25	05 26	05 27	05 28	05 29	05 30	05 31	05 33	05 34	05 35	05 36	05 37	05 38	05 39	05 40
N 10	42	05 43	05 43	05 44	05 45	05 46	05 46	05 47	05 48	05 48	05 49	05 49	05 50	05 50	05 50	05 51	05 51
0	05 59	06 00	06 01	06 01	06 02	06 02	06 02	06 02	06 03	06 03	06 03	06 03	06 03	06 02	06 02	06 02	06 01
S 10	06 17	17	18	18	18	18	18	18	18	17	17	16	15	15	14	12	11
20	35	35	36	36	36	35	35	34	34	33	32	30	29	27	26	24	22
S 30	06 56	06 56	06 56	06 56	06 56	06 55	06 54	06 53	06 52	06 50	06 48	06 46	06 44	06 42	06 40	06 37	06 34
35	07 09	07 08	07 08	07 08	07 07	07 06	07 05	07 04	07 02	07 00	06 58	06 56	06 53	06 50	47	44	41
40	23	23	22	22	21	19	18	16	14	12	07 09	07 06	07 03	07 00	06 56	06 53	49
45	07 39	39	39	38	36	35	33	31	28	25	22	19	15	11	07 07	07 03	06 58
50	08 00	07 59	07 59	07 57	07 56	07 54	07 51	48	45	42	38	34	29	25	20	14	07 09
S 52	08 10	08 09	08 08	08 07	08 05	08 03	08 00	07 57	07 53	07 49	07 45	07 41	07 36	07 31	07 25	07 20	07 14
54	21	20	19	17	15	13	09	08 06	08 02	07 58	07 53	48	43	38	32	26	20
56	33	33	31	29	27	24	20	16	12	08 07	08 02	07 57	07 51	45	39	33	26
58	08 48	08 47	08 45	43	40	37	33	28	24	18	13	08 07	08 01	07 54	47	40	33
S 60	09 05	09 04	09 02	08 59	08 56	08 52	08 48	08 43	08 37	08 31	08 25	08 18	08 11	08 04	07 56	07 49	07 41

SUNSET

Lat.	June	July											August				
	28	1	4	7	10	13	16	19	22	25	28	31	3	6	9	12	15
°	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
N 72	▭	▭	▭	▭	▭	▭	▭	▭	▭	▭	▭	▭	▭	23 08	22 33	22 06	21 43
70	▭	▭	▭	▭	▭	▭	▭	▭	▭	▭	23 29	22 52	22 27	22 06	21 46	21 29	21 12
68	▭	▭	▭	▭	▭	▭	▭	23 22	22 56	22 35	22 18	22 01	21 46	21 31	21 17	21 03	20 49
66	▭	23 44	23 25	23 10	22 56	22 43	22 31	22 18	22 06	21 54	21 42	21 30	21 18	21 07	20 55	20 43	31
64	22 20	22 26	22 21	22 15	22 08	22 01	21 53	21 44	21 36	26	21 17	21 07	20 57	20 47	37	27	17
62	21 53	21 50	21 47	21 43	21 38	21 33	27	20	21 13	21 05	20 57	20 49	41	32	23	14	20 05
N 60	21 27	21 25	21 23	21 20	21 16	21 11	21 06	21 01	20 55	20 48	20 41	20 34	20 27	20 19	20 11	20 03	19 55
58	21 07	21 05	21 03	21 01	20 58	20 54	20 50	20 45	39	34	28	21	15	20 08	20 01	19 53	40
56	20 50	20 49	20 47	20 45	43	39	36	31	27	22	16	10	20 04	19 58	19 52	45	38
54	36	35	34	32	30	27	23	20	15	11	20 06	20 01	19 55	50	44	38	31
52	24	23	22	20	18	16	13	09	20 06	20 02	19 57	19 52	47	42	37	31	25
N 50	20 13	20 12	20 11	20 10	20 08	20 06	20 03	20 00	19 57	19 53	19 49	19 45	19 40	19 35	19 30	19 25	19 19
45	19 51	19 50	19 50	19 49	19 47	19 46	19 43	19 41	38	35	32	29	25	21	17	12	19 07
40	33	33	32	32	30	29	27	26	23	21	18	15	12	19 09	19 05	19 01	18 57
35	18	18	18	17	16	15	14	13	11	19 09	19 07	19 04	19 02	18 59	18 56	18 52	49
30	19 05	19 05	19 05	19 05	19 04	19 03	19 02	19 01	19 00	18 58	18 56	18 54	18 52	50	47	44	42
N 20	18 43	18 43	18 43	18 43	18 43	18 43	18 43	18 42	18 41	18 40	18 39	18 38	18 36	18 35	18 33	18 31	18 29
N 10	24	25	25	25	26	26	26	25	25	24	24	23	22	21	20	19	18
0	18 07	18 07	18 08	18 08	18 09	18 09	18 10	18 10	18 10	18 10	18 10	18 10	18 10	18 09	18 09	18 08	18 08
S 10	17 49	17 50	17 51	17 52	17 52	17 53	17 54	17 54	17 55	17 56	17 56	17 56	17 57	17 57	17 58	17 58	17 58
20	31	32	33	34	35	36	37	38	39	40	41	43	44	45	45	46	47
S 30	17 10	17 11	17 12	17 14	17 15	17 16	17 18	17 20	17 21	17 23	17 25	17 27	17 29	17 30	17 32	17 34	17 35
35	16 58	16 59	17 00	17 02	17 03	17 05	17 07	17 09	17 11	13	15	17	20	22	24	26	28
40	44	45	16 46	16 48	16 50	16 52	16 54	16 57	16 59	17 02	17 04	17 07	17 10	12	15	18	21
45	27	28	30	32	34	37	39	42	45	16 48	16 51	16 55	16 58	17 01	17 05	17 08	12
50	16 06	16 08	10	13	15	18	21	25	28	32	36	40	44	16 48	16 52	16 56	17 01
S 52	15 56	15 58	16 00	16 03	16 06	16 09	16 12	16 16	16 20	16 24	16 28	16 33	16 37	16 42	16 46	16 51	16 56
54	45	47	15 50	15 52	15 56	15 59	16 03	16 07	11	15	20	25	30	35	40	45	50
56	33	35	38	41	44	48	15 52	15 56	16 01	16 06	11	16	22	27	33	38	44
58	18	21	23	27	31	35	39	44	15 50	15 55	16 01	16 07	12	18	25	31	37
S 60	15 01	15 04	15 07	15 10	15 15	15 20	15 25	15 30	15 36	15 42	15 49	15 55	16 02	16 09	16 15	16 22	16 29

This 6-minute period is the difference in time between sunrise at 35 °N and sunrise at 37 °N. Add the 6 minutes to the time of sunrise at 35 °N. This gives you the time of sunrise at 37 °N (04:40 + :06 = 04:46 LMT).

EXAMPLE 3: Find the time of sunrise at 60 °N on 24 July. Note that 24 July is not listed in the table. If the date is not listed, you must interpolate the time. To determine sunrise at 60 °N on 24 July, use the times of sunrise for the dates listed on either side of the 24th; that is, 22 and 25 July.

LATITUDE TIME

22 = 03:17

3 — 24 = X — :07

1 — X

25 = 03:24

Again, you must set up a ratio. This time the ratio is one of time versus days. The factors are X (the unknown time between 03:17 and 03:24), :07 (the total time difference between 03:17 and 03:24), 1 (the difference in days between the 24th and 25th), and 3 (the number of days between the 22d and 25th).

$$\frac{X}{:07} = \frac{1}{3}$$

$$3X = :07$$

$$X = :02 \text{ (rounded off)}$$

There is a 2-minute difference between the time of sunrise on the 24th and the time of sunrise on the 25th of July. Subtract the 2 minutes from the time of sunrise on the 25th. Sunrise occurs at 03:22 LMT on the 24th.

EXAMPLE 4: Find the time of sunrise for a station along 53 °N on 15 July. Note that neither 53 °N nor 15 July is listed in the table. This requires interpolation of the time for both the latitude and the date. First, find the sunrise times for 52 °N and 54 °N on 13 and 16 July, as follows:

LAT.	13TH	16TH
54 °N	03:44	03:48
53 °N	X	X
52 °N	03:55	03:59

A quick look at the time difference between 54 °N and 52 °N on the 13th and the 16th shows that there is an 11-minute difference on both days. Since 53 °N falls halfway between 52 °N and 54 °N, the time of sunrise at 53 °N will fall halfway between the time of sunrise for 52 °N and the time of sunrise for 54 °N; that is, 03:49:30 on the 13th and 03:53:30 on the 16th. These times equate to one-half of the 11-minute time difference.

The next step is to interpolate the time between the dates.

DATE = TIME

13 = 03:50 (rounded off)

15 = X

16 = 03:54 (rounded off)

$$\frac{1}{3} = \frac{X}{:04}$$

$$3X = :04$$

$$X = :01 \text{ (rounded off)}$$

Subtract :01 from the time of sunrise on the 16th: 03:54 − :01 = 03:53 LMT. This is the time of sunrise on 15 July.

Learning Objective: Identify the procedures used in converting LMT to LST and UTC.

CONVERTING TIME

As I stated earlier, the times you take or compute from the Sunrise and Sunset tables are in LMT and must be converted into LST or UTC. The conversion to LST is accomplished using the longitude of the location for which you are computing sunrise and sunset, the standard meridian closest to this longitude, and table 6-7-2, Conversion of Arc to Time.

The conversion steps are as follows:

Step 1. Determine the longitude of the standard meridian closest to the longitude of the location for which you are computing sunrise and sunset. Remember, the standard meridians are every 15 degrees either side of the Prime meridian (0 °).

Table 6-7-2.—Conversion of Arc to Time

CONVERSION OF ARC TO TIME

°	h m	°	h m	°	h m	°	h m	°	h m	°	h m	′	m s
0	0 00	60	4 00	120	8 00	180	12 00	240	16 00	300	20 00	0	0 00
1	0 04	61	4 04	121	8 04	181	12 04	241	16 04	301	20 04	1	0 04
2	0 08	62	4 08	122	8 08	182	12 08	242	16 08	302	20 08	2	0 08
3	0 12	63	4 12	123	8 12	183	12 12	243	16 12	303	20 12	3	0 12
4	0 16	64	4 16	124	8 16	184	12 16	244	16 16	304	20 16	4	0 16
5	0 20	65	4 20	125	8 20	185	12 20	245	16 20	305	20 20	5	0 20
6	0 24	66	4 24	126	8 24	186	12 24	246	16 24	306	20 24	6	0 24
7	0 28	67	4 28	127	8 28	187	12 28	247	16 28	307	20 28	7	0 28
8	0 32	68	4 32	128	8 32	188	12 32	248	16 32	308	20 32	8	0 32
9	0 36	69	4 36	129	8 36	189	12 36	249	16 36	309	20 36	9	0 36
10	0 40	70	4 40	130	8 40	190	12 40	250	16 40	310	20 40	10	0 40
11	0 44	71	4 44	131	8 44	191	12 44	251	16 44	311	20 44	11	0 44
12	0 48	72	4 48	132	8 48	192	12 48	252	16 48	312	20 48	12	0 48
13	0 52	73	4 52	133	8 52	193	12 52	253	16 52	313	20 52	13	0 52
14	0 56	74	4 56	134	8 56	194	12 56	254	16 56	314	20 56	14	0 56
15	1 00	75	5 00	135	9 00	195	13 00	255	17 00	315	21 00	15	1 00
16	1 04	76	5 04	136	9 04	196	13 04	256	17 04	316	21 04	16	1 04
17	1 08	77	5 08	137	9 08	197	13 08	257	17 08	317	21 08	17	1 08
18	1 12	78	5 12	138	9 12	198	13 12	258	17 12	318	21 12	18	1 12
19	1 16	79	5 16	139	9 16	199	13 16	259	17 16	319	21 16	19	1 16
20	1 20	80	5 20	140	9 20	200	13 20	260	17 20	320	21 20	20	1 20
21	1 24	81	5 24	141	9 24	201	13 24	261	17 24	321	21 24	21	1 24
22	1 28	82	5 28	142	9 28	202	13 28	262	17 28	322	21 28	22	1 28
23	1 32	83	5 32	143	9 32	203	13 32	263	17 32	323	21 32	23	1 32
24	1 36	84	5 36	144	9 36	204	13 36	264	17 36	324	21 36	24	1 36
25	1 40	85	5 40	145	9 40	205	13 40	265	17 40	325	21 40	25	1 40
26	1 44	86	5 44	146	9 44	206	13 44	266	17 44	326	21 44	26	1 44
27	1 48	87	5 48	147	9 48	207	13 48	267	17 48	327	21 48	27	1 48
28	1 52	88	5 52	148	9 52	208	13 52	268	17 52	328	21 52	28	1 52
29	1 56	89	5 56	149	9 56	209	13 56	269	17 56	329	21 56	29	1 56
30	2 00	90	6 00	150	10 00	210	14 00	270	18 00	330	22 00	30	2 00
31	2 04	91	6 04	151	10 04	211	14 04	271	18 04	331	22 04	31	2 04
32	2 08	92	6 08	152	10 08	212	14 08	272	18 08	332	22 08	32	2 08
33	2 12	93	6 12	153	10 12	213	14 12	273	18 12	333	22 12	33	2 12
34	2 16	94	6 16	154	10 16	214	14 16	274	18 16	334	22 16	34	2 16
35	2 20	95	6 20	155	10 20	215	14 20	275	18 20	335	22 20	35	2 20
36	2 24	96	6 24	156	10 24	216	14 24	276	18 24	336	22 24	36	2 24
37	2 28	97	6 28	157	10 28	217	14 28	277	18 28	337	22 28	37	2 28
38	2 32	98	6 32	158	10 32	218	14 32	278	18 32	338	22 32	38	2 32
39	2 36	99	6 36	159	10 36	219	14 36	279	18 36	339	22 36	39	2 36
40	2 40	100	6 40	160	10 40	220	14 40	280	18 40	340	22 40	40	2 40
41	2 44	101	6 44	161	10 44	221	14 44	281	18 44	341	22 44	41	2 44
42	2 48	102	6 48	162	10 48	222	14 48	282	18 48	342	22 48	42	2 48
43	2 52	103	6 52	163	10 52	223	14 52	283	18 52	343	22 52	43	2 52
44	2 56	104	6 56	164	10 56	224	14 56	284	18 56	344	22 56	44	2 56
45	3 00	105	7 00	165	11 00	225	15 00	285	19 00	345	23 00	45	3 00
46	3 04	106	7 04	166	11 04	226	15 04	286	19 04	346	23 04	46	3 04
47	3 08	107	7 08	167	11 08	227	15 08	287	19 08	347	23 08	47	3 08
48	3 12	108	7 12	168	11 12	228	15 12	288	19 12	348	23 12	48	3 12
49	3 16	109	7 16	169	11 16	229	15 16	289	19 16	349	23 16	49	3 16
50	3 20	110	7 20	170	11 20	230	15 20	290	19 20	350	23 20	50	3 20
51	3 24	111	7 24	171	11 24	231	15 24	291	19 24	351	23 24	51	3 24
52	3 28	112	7 28	172	11 28	232	15 28	292	19 28	352	23 28	52	3 28
53	3 32	113	7 32	173	11 32	233	15 32	293	19 32	353	23 32	53	3 32
54	3 36	114	7 36	174	11 36	234	15 36	294	19 36	354	23 36	54	3 36
55	3 40	115	7 40	175	11 40	235	15 40	295	19 40	355	23 40	55	3 40
56	3 44	116	7 44	176	11 44	236	15 44	296	19 44	356	23 44	56	3 44
57	3 48	117	7 48	177	11 48	237	15 48	297	19 48	357	23 48	57	3 48
58	3 52	118	7 52	178	11 52	238	15 52	298	19 52	358	23 52	58	3 52
59	3 56	119	7 56	179	11 56	239	15 56	299	19 56	359	23 56	59	3 56

The above table is for converting expressions in arc to their equivalent in time; its main use in this Almanac is for the conversion of longitude for application to L.M.T. (*added* if *west*, *subtracted* if *east*) to give G.M.T., or vice versa, particularly in the case of sunrise, sunset, etc.

Step 2. Compute the difference between the longitude of the closer standard meridian and the location's longitude.

Step 3. Enter the Conversion of Arc to Time table with the longitude difference obtained in step 2, and convert degrees and minutes into time. The conversion factor is 1 degree equals 4 minutes. The last two columns are used to convert minutes of longitude (′) into minutes and seconds of time.

Step 4. Add the time obtained in step 3 to or subtract it from the LMT. Add if the longitude of interest is west of the closer standard meridian, or subtract if it is east of the closer standard meridian.

For example, let's use a sunrise time of 06:50 LMT as computed for NAS Pensacola, Florida, (30°21′N, 87°19′W).

Step 1. The standard meridian closest to 87°19′W is 90°W.

Step 2. The difference between 90°W and 87°19′W is 2°41′.

Step 3. Enter the conversion table and convert 2°41′ into time. The 2° equals 8 minutes, and 41′ equals 2 minutes 44 seconds (3 minutes rounded off). IF THE SECONDS VALUE IS 30 OR GREATER, YOU ROUND UP. You should find 11 minutes.

Step 4. Subtract 11 minutes from 06:50 LMT (06:50 − :11 = 06:39 LST).

To convert Local Mean Time into Universal Time Coordinated, you simply enter the Conversion of Arc to Time table with the longitude of the location for which you are determining sunrise and sunset. For example, if you are computing sunrise or sunset for NAS Pensacola, you must convert 87°19′W into time. From table 6-7-2, 87° equals 5 hours 48 minutes, and 19′ equals 1 minute and 16 seconds, for a total time difference of 5 hours 49 minutes 16 seconds (5:49, rounded off). This time difference is then added to or subtracted from the LMT to get UTC. When the longitude is west of the prime meridian, the time is added. When the longitude is east of the prime meridian, the time is subtracted.

Learning Objective: Define twilight and identify the tables and procedures used in twilight computations.

MORNING AND EVENING TWILIGHT

The Sun's rays penetrate and brighten the sky before sunrise and after sunset. These are the twilight periods. There are three stages of twilight.

Civil Twilight is the period before sunrise and after sunset until the time when the center of the disk of the sun is 6 degrees below the horizon. When you calculate civil twilight using the appropriate table in *Air Almanac*, you are actually calculating "Beginning-of-Morning Civil Twilight" (BMCT) for the time of civil twilight preceding sunrise, and "End-of-Evening Civil Twilight" (EECT) for the time of civil twilight following sunset. During the civil twilight period, stars and planets of the first magnitude may be visible. Only the brightest stars and planets will be noticeable during BMCT and EECT. During the civil twilight period, civilians and military troops can carry on all normal daytime activities without being hindered by any loss of natural illumination.

The next stage of twilight is Nautical Twilight. This is the period between civil twilight and the time at which the center of the disk of the sun is 12 degrees below the horizon. The Nautical Twilight tables yield times for "Beginning-of-Morning Nautical Twilight" (BMNT) and "End-of-Evening Nautical Twilight" (EENT). During the period of nautical twilight, stars and planets of the second to fifth magnitude may be visible. Available illumination is described as "approaching conditions expected under full light of day." Civilians and military troops may continue most daytime activities without noticeable hindrance except at the time of EENT and BMNT when the Sun illuminates only a trace of a bright band on the horizon. Most people will need supplemental lighting to carry on normal outdoor activity before BMNT and after EENT. "Beginning-of-morning nautical twilight" and "end-of-evening nautical twilight" are the terms usually being referred to when people use the generic terms *twilight*, *first light*, and *last light*.

The last stage of twilight is the period between nautical twilight and the time the Sun reaches a position 18 degrees below the horizon. This period is called Astronomical Twilight. The times of

astronomical twilight are referred to as "Beginning-of-Morning Astronomical Twilight" (BMAT) and "End-of-Evening Astronomical Twilight" (EEAT). Stars of the sixth magnitude may be visible during the astronomical twilight period. There is no trace of any bright band of sky on the horizon at the time of BMAT and EEAT. During the nighttime period after EEAT and before BMAT, it is, without question, DARK. Unless lunar illumination is available, movement of either civilians or military troops without the aid of artificial lighting, Night Vision devices, or sight-substitute devices cannot be done.

The Twilight tables are similar to the Sunrise and Sunset tables. See table 6-7-3. The twilight tables are used to obtain the times of first light (morning) and last light (evening) for latitudes 72°N through 60°S.

Learning Objective: Identify the tables and procedures used to compute sunrise, sunset, and twilight for locations north of 72°N.

SUNLIGHT AND TWILIGHT GRAPHS

The Sunlight and Twilight graphs (table 6-7-4) are used to compute sunrise, sunset, and twilight for latitudes north of 72°N. As you can see, the table consists of two sets of graphs; the top two graphs are the Semiduration of Sunlight graphs, and the lower two graphs are the Duration of Twilight graphs.

Semiduration of Sunlight Graphs

The Semiduration of Sunlight graphs are the top two graphs of table 6-7-4. The upper graph covers the first 6 months of the year, and the lower graph covers the last 6 months. The months are broken down into 5-day increments across the bottom of the graphs. The latitudes 65°N to 90°N are listed on the sides, and a listing of Local Mean Times lies across the top.

The curved or skewed lines in the graphs are the semiduration-of-sunlight lines—*semiduration* meaning one-half of the total daylight period on a particular date. The semiduration line labeled 6, for example, indicates that there are 6 hours of daylight between the time of sunrise and noon LMT (one-half of the total time of daylight) and 6 hours between noon LMT and sunset (the other one-half of the daylight period).

Two areas of each graph are without semiduration lines. The area to the left above the 0-hour semiduration line on the upper graph and the area to the right above the O-hour semiduration line on the lower graph are labeled "Sun Below Horizon." If the intersection of a latitude and date falls within these areas, it means the Sun would remain below the horizon throughout the day at that latitude; sunrise would not occur. The area to the right above the 12-hour semiduration line on the upper graph and the area to the left above the 12-hour semiduration line on the lower graph are labeled "Sun Above Horizon." If the intersection of a latitude and date falls within these areas, the Sun would remain above the horizon throughout the day at that latitude; the Sun would not set.

Let's try a couple of dates and latitudes and see how to use this graph to determine the times of sunrise and sunset.

EXAMPLE 1: Date, July 16; latitude, 70°N.

Step 1. Locate 16 July along the date scale at the bottom of the lower graph and extend a line vertically to the top of the graph.

Step 2. Locate latitude 70°N and extend a line horizontally across the graph.

Step 3. Where the two lines intersect, read the semiduration period.

In example 1, the point of intersection falls within the "Sun Above Horizon" area. On this date at this latitude, the Sun does not set; it stays above the horizon all day.

EXAMPLE 2: Date, 21 September; latitude, 75°N.

Step 1. Locate 21 September along the date scale on the lower graph and extend a line vertically so that it intersects the time scale at the top of the graph.

Step 2. Read the time of meridian passage at the point where the date line intersects the time scale. The time is 11:53 LMT.

Step 3. Locate 75°N and extend a line horizontally across the graph to intersect the date line.

Step 4. At the point of intersection, read the semiduration period. Since the point of intersection falls approximately halfway between the

Table 6-7-3.—Sample Page of Civil Twilight Data

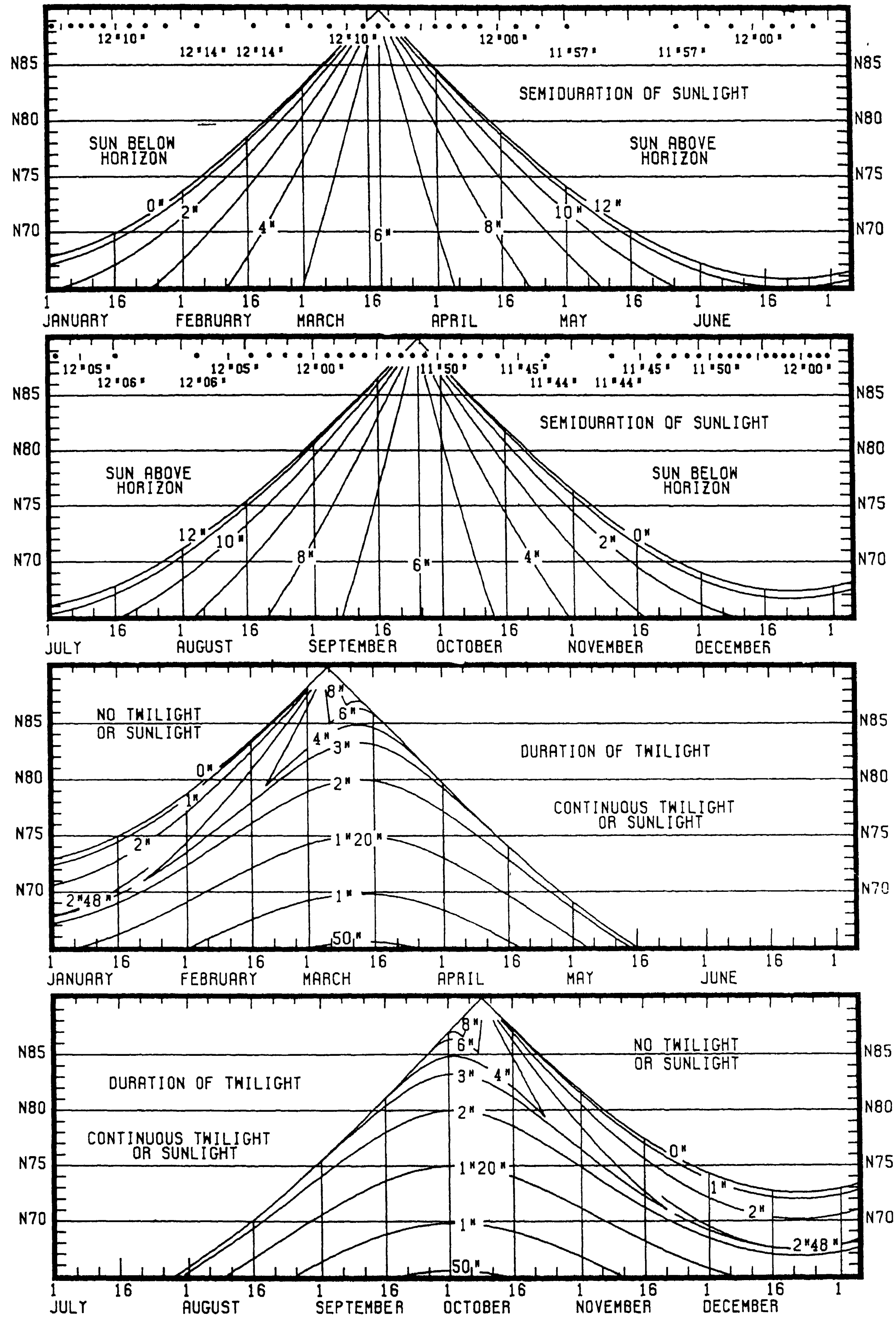
MORNING CIVIL TWILIGHT

Lat.	June	July											August			
	28	1	4	7	10	13	16	19	22	25	28	31	3	6	9	12
°	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h
N 72	▭	▭	▭	▭	▭	▭	▭	▭	▭	▭	▭	▭	▭	////	////	///
70	▭	▭	▭	▭	▭	▭	▭	▭	▭	▭	////	////	////	////	////	///
68	▭	▭	▭	▭	▭	▭	▭	////	////	////	////	////	////	////	////	01
66	▭	////	////	////	////	////	////	////	////	////	////	////	00 45	01 19	01 42	02
64	////	////	////	////	////	////	////	////	////	00 36	01 08	01 30	01 48	02 04	02 18	
62	////	////	////	////	////	00 24	00 53	01 12	01 28	01 43	01 56	02 09	02 21	32	02 44	02
N 60	00 55	01 02	01 09	01 18	01 27	01 36	01 46	01 56	02 06	02 16	02 25	02 35	02 45	02 54	03 03	03
58	01 44	01 48	01 52	01 57	02 03	02 10	02 17	02 24	32	39	02 47	02 55	03 03	03 11	19	
56	02 14	02 16	02 20	02 24	29	34	39	02 45	02 52	02 58	03 05	03 12	19	25	32	
54	36	38	41	02 44	02 48	02 53	02 58	03 03	03 08	03 14	20	26	32	38	44	
52	02 53	02 56	02 58	03 01	03 05	03 09	03 13	17	22	27	32	37	43	48	03 54	03
N 50	03 08	03 10	03 13	03 15	03 19	03 22	03 26	03 30	03 34	03 39	03 43	03 48	03 53	03 58	04 03	04
45	03 38	03 39	03 41	03 44	03 46	03 49	03 52	03 55	03 59	04 02	04 06	04 09	04 13	04 17	21	
40	04 00	04 02	04 03	04 05	04 07	04 10	04 12	04 15	04 17	20	23	26	29	32	36	
35	18	20	21	23	25	26	29	31	33	35	38	40	43	45	48	04
30	34	35	04 36	04 37	04 39	04 41	04 42	04 44	04 46	04 48	04 50	04 52	04 54	04 56	04 58	05
N 20	04 59	04 59	05 00	05 01	05 03	05 04	05 05	05 06	05 08	05 09	05 10	05 11	05 12	05 14	05 15	05
N 10	05 19	05 20	20	21	22	23	24	24	25	26	27	27	28	28	28	
0	37	38	38	39	39	40	40	40	41	41	41	41	41	41	41	
S 10	05 54	05 54	05 55	05 55	05 55	05 56	05 56	05 56	05 55	05 55	05 55	05 54	05 53	05 53	05 52	05
20	06 11	06 11	06 12	06 12	06 12	06 12	06 11	06 11	06 10	06 09	06 08	06 07	06 06	06 04	06 03	06
S 30	06 30	06 30	06 30	06 30	06 30	06 29	06 28	06 27	06 26	06 25	06 23	06 21	06 19	06 17	06 15	06
35	40	41	40	40	39	39	38	36	35	33	31	29	26	24	21	
40	06 52	06 52	06 52	06 51	06 50	06 49	06 48	46	45	42	40	37	34	31	28	
45	07 06	07 05	07 05	07 04	07 03	07 02	07 00	06 58	06 56	06 53	06 50	47	43	40	36	
50	21	21	21	19	18	16	14	07 12	07 09	07 05	07 02	06 58	54	50	45	
S 52	07 29	07 29	07 28	07 27	07 25	07 23	07 21	07 18	07 15	07 11	07 07	07 03	06 59	06 54	06 49	06
54	37	37	36	34	32	30	28	25	21	17	13	09	07 04	06 59	54	
56	46	46	44	43	41	38	36	32	28	24	20	15	10	07 04	06 59	
58	07 56	07 56	07 54	07 53	07 50	48	44	41	36	32	27	22	16	10	07 04	06
S 60	08 08	08 07	08 06	08 04	08 01	07 58	07 54	07 50	07 45	07 41	07 35	07 29	07 23	07 17	07 10	07

EVENING CIVIL TWILIGHT

Lat.	June	July											August			
	28	1	4	7	10	13	16	19	22	25	28	31	3	6	9	1.
°	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h
N 72	▭	▭	▭	▭	▭	▭	▭	▭	▭	▭	▭	▭	▭	////	////	//
70	▭	▭	▭	▭	▭	▭	▭	▭	▭	▭	////	////	////	////	////	//
68	▭	▭	▭	▭	▭	▭	▭	////	////	////	////	////	////	////	23 32	22
66	▭	////	////	////	////	////	////	////	////	////	////	////	23 15	22 46	22 23	22
64	////	////	////	////	////	////	////	////	////	23 24	22 57	22 37	22 20	22 04	21 49	21
62	////	////	////	////	////	23 36	23 12	22 55	22 40	22 26	22 13	22 01	21 48	21 36	25	21
N 60	23 09	23 03	22 57	22 49	22 41	22 32	22 23	22 14	22 04	21 55	21 45	21 35	21 25	21 16	21 06	20
58	22 21	22 19	22 15	22 11	22 05	22 00	21 53	21 46	21 39	31	23	21 15	21 07	20 59	20 50	
56	21 52	21 50	21 48	21 44	21 41	21 36	31	25	19	21 13	21 06	20 59	20 52	45	37	
54	30	29	27	24	21	17	21 13	21 08	21 03	20 58	20 52	46	39	33	26	
52	21 12	21 11	21 10	21 08	21 05	21 02	20 58	20 54	20 49	45	39	34	28	22	16	
N 50	20 57	20 57	20 55	20 53	20 51	20 48	20 45	20 42	20 38	20 33	20 29	20 24	20 18	20 13	20 07	20
45	28	28	27	25	24	22	20 19	20 17	20 13	20 10	20 06	20 02	19 58	19 54	19 49	19
40	20 06	20 05	20 05	20 04	20 03	20 01	19 59	19 57	19 55	19 52	19 49	19 46	42	39	35	
35	19 48	19 47	19 47	19 47	19 46	19 44	43	41	39	37	35	32	29	26	23	
30	32	32	32	32	31	30	29	28	26	25	23	20	18	19 15	19 13	19
N 20	19 08	19 08	19 08	19 08	19 08	19 07	19 07	19 06	19 05	19 04	19 03	19 01	19 00	18 58	18 56	18
N 10	18 47	18 48	18 48	18 48	18 48	18 48	18 48	18 48	18 47	18 47	18 46	18 45	18 45	43	42	
0	29	30	30	31	31	31	32	32	32	32	32	32	31	31	30	
S 10	18 12	18 13	18 14	18 14	18 15	16	16	17	17	18	18	19	19	19	19	
20	17 55	17 56	17 57	17 58	17 59	18 00	18 01	18 02	18 03	18 04	18 05	18 06	18 07	18 07	18 08	18
S 30	17 36	17 37	17 38	17 40	17 41	17 42	17 44	17 45	17 47	17 49	17 50	17 52	17 54	17 55	17 57	17
35	26	27	28	30	31	33	35	36	38	40	42	44	46	48	50	
40	14	15	17	18	20	22	24	26	29	31	33	36	38	41	43	
45	17 01	17 02	17 04	17 05	17 08	17 10	17 12	15	17	20	23	26	29	32	36	
50	16 45	16 46	16 48	16 50	16 53	16 55	16 58	17 01	17 04	08	11	15	19	23	26	
S 52	16 37	16 39	16 41	16 43	16 46	16 49	16 52	16 55	16 59	17 02	17 06	17 10	17 14	17 18	17 22	17
54	29	31	33	35	38	41	45	48	52	16 56	17 00	17 04	09	13	18	
56	20	22	24	27	30	33	37	41	45	49	16 54	16 58	17 03	08	13	
58	16 10	12	14	17	21	24	28	32	37	42	46	52	16 57	17 02	08	
S 60	15 58	16 01	16 03	16 06	16 10	16 14	16 18	16 23	16 28	16 33	16 38	16 44	16 50	16 56	17 02	17

Table 6-7-4.—Sunlight and Twilight Graphs



6-hour and 7-hour lines, we'll call the semiduration period 6 1/2 hours.

Step 5. Subtract 6 1/2 hours from the time of meridian passage to find the time of sunrise and add 6 1/2 hours to find the time of sunset, as follows:

11:53 LMT − 6:30 = 05:23 LMT (sunrise)

11:53 LMT + 6:30 = 18:23 LMT (sunset)

EXAMPLE 3: Date, 1 November; latitude, 79 °N.

Step 1. Locate 1 November along the date scale at the bottom of the lower graph and extend a line vertically to the top of the graph.

Step 2. Locate 79 °N and extend a line horizontally to intersect the date line.

Step 3. At the point of intersection read the semiduration period of sunlight. Since the intersection point in this example falls in the area of Sun Below Horizon, the Sun will not rise above the horizon at this latitude. There will be no sunrise or sunset on this date at this particular latitude.

Duration of Twilight Graphs

The Duration of Twilight graphs (the lower two graphs of table 6-7-4) are very similar to the Semiduration of Sunlight graphs in that they consist of a date scale, a latitude scale, and skewed semiduration lines. Two areas on each of these graphs also are without semiduration lines. On the left above the 0-hour semiduration line on the upper Twilight graph and on the right above the O-hour semiduration line on the lower graph are the areas of "No Twilight or Sunlight." On the right above the 8-hour semiduration line on the upper Twilight graph and on the left above the 8-hour semiduration line on the lower graph are the "Continuous Twilight or Sunlight" areas.

The Duration of Twilight graphs are used to determine the beginning and ending of civil twilight. When a latitude and date intersect within the span of semiduration lines, you must determine the semiduration period. The semiduration time is one-half of the total twilight time. On the upper Twilight graph of table 6-7-4, Duration of Twilight January to July, note that each semiduration line is labeled and that there are two 1-hour time lines and two 2-hour time lines. Also, note that just above the 3-hour time line on the right side of the graph, some of the lines run together at various points. If you align these points, the line that is formed will correspond to the 0-hour duration line of the Semiduration of Sunlight graph. Along this line, sunrise may or may not occur. To the right of this line, the time represents one-half of the total duration of twilight when the Sun remains below the horizon. The sky lightens but the Sun does not rise above the horizon. To the left of this line, the time represents the length of each twilight period (morning and evening) for each day having a sunrise.

For further explanation on how to use these graphs, let's do an example: Date, 26 October; latitude, 77 °N.

Step 1. Locate 26 October along the date scale on the lower graph and extend a line vertically to the top of the graph.

Step 2. Locate 77° and extend a line horizontally until it intersects the line drawn in step 1.

Step 3. Where the two lines intersect, read the duration of twilight. In this example, the duration of twilight on 26 October is approximately 2 hours and 15 minutes.

Note: The attainable accuracy for twilight time using these graphs is no greater than ±15 minutes.

Step 4. Subtract 2 hours and 15 minutes from the time of sunrise to obtain the time of first light, and add 2 hours and 15 minutes to the time of sunset to obtain the time of last light. REMEMBER: THE TIMES ARE LMT AND MUST BE CONVERTED TO LST OR UTC.

To further your knowledge of sunrise, sunset, and twilight, I recommend that you refer to the latest addition of *Air Almanac*. You may also want to complete the Practical Training Publication *Preparation of Astronomical and Tidal Data*, NAVEDTRA 40390-A.

PRACTICAL TRAINING EXERCISE

Obtain the current *Air Almanac* and compute the time of sunrise, sunset, and twilight for the following locations:

1. Your station, tomorrow
2. Adak, Alaska (51°53′N, 176°39′W) on 22 January
3. Bermuda (32°22′N, 64°41′W) on 2 April
4. Thule, Greenland (77°29′N, 69°12′W) on 21 October
5. Vladivostok, U.S.S.R. (43°07′N, 131°54′E) on 7 December

Have your immediate supervisor or leading chief answer any questions you may have, and then have one of them check your computations.

UNIT 6—LESSON 8

COMPUTING MOONRISE AND MOONSET AND PERCENT ILLUMINATION

OVERVIEW	OUTLINE
Identify the phases of the Moon.	Phases of the Moon
Identify the two factors in the Moon's orbit that cause daily changes in the time of moonrise and moonset.	Orbital factors affecting moonrise and moonset
Identify the source providing specific times of moonrise and moonset.	*Air Almanac*
Identify the steps used to compute moonrise and moonset using *Air Almanac*.	Moonrise and moonset computations
Relate the age of the Moon, in days, to the percent illumination available.	Lunar percent illumination

COMPUTING MOONRISE AND MOONSET

The strength of moonlight varies depending on the phase of the Moon and on Earth's cloud cover. Because naval operations take place at night as well as during the day, information on the amount of light that the operations will be exposed to becomes important. Although several programs are readily available that calculate Sunrise, Sunset, Moonrise, Moonset, and percent Lunar Illumination, you must know the procedure to calculate these figures using the tables. While the process presented here refers to *Air Almanac*, the data may also be computed in a similar manner using *Nautical Almanac*.

Learning Objective: Identify the phases of the Moon.

PHASES OF THE MOON

It takes the Moon approximately 29 1/2 days to make one complete orbit of Earth. During these 29 1/2 days, we here on Earth see what we regard as the phases of the moon. When the Moon is in its New phase, the Moon's orbit carries it directly between Earth and the Sun. See figure 6-8-1. The side of the Moon facing Earth is in darkness. There is no moonlight. Just the opposite occurs when the Moon enters its Full phase. Now Earth

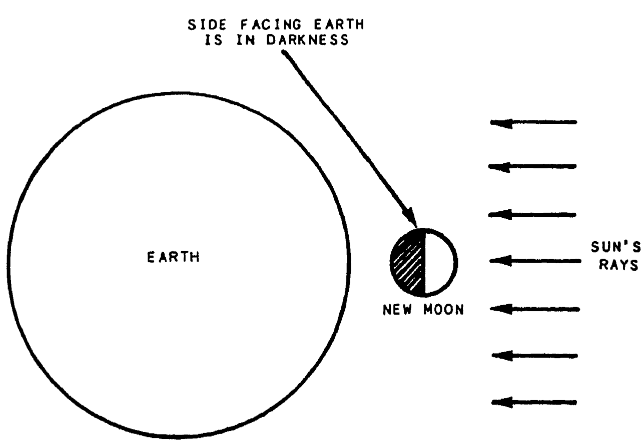


Figure 6-8-1.—Earth-Moon-Sun relationship during New Moon phase.

is between the Moon and the Sun. The side facing Earth is now totally illuminated, while the side facing away from Earth is in darkness. See figure 6-8-2.

Starting with the New Moon, the Moon passes through the following phases as it orbits Earth: New Moon, 1st-quarter Moon, Half-Moon, 2d-quarter Moon, Full Moon, 3d-quarter Moon, Half-Moon, 4th-quarter Moon, and New Moon. Figure 6-8-3 shows the moon phases as they occurred between 5 January 1989 and 3 February 1989.

The times of moonrise and moonset can be estimated by timing the passage of the Moon across the nighttime sky during a particular phase. Each phase has its own time relationship with regard to crossing the meridian of the nighttime sky. For example, during a Full Moon, the Moon reaches the meridian approximately 6 hours after rising. From the meridian, it takes 6 more hours to set. The reason the time of moonrise and moonset can only be estimated using the phases of the Moon is the Moon's orbit. It is NOT constant about Earth. Changes in the orbit cause changes in the times of moonrise and moonset.

Learning Objective: Identify the two factors in the Moon's orbit that cause daily changes in the time of moonrise and moonset.

ORBITAL FACTORS AFFECTING MOONRISE AND MOONSET

Two factors in the Moon's orbit change the times of moonrise and moonset on a daily basis: (1) the Moon's orbital angle and (2) its orbital speed.

Orbital Angle

The Moon crosses the equator twice during each revolution. It crosses the equator while moving north and crosses it again while moving south during each revolution. The angle at which the Moon crosses the equator is known as the Moon's ecliptic orbit angle. This angle varies between 18 1/2° and 28 1/2° over a period of a little more than 18 years. The mean angle is 23 1/2°. This variation is illustrated in figure 6-8-4.

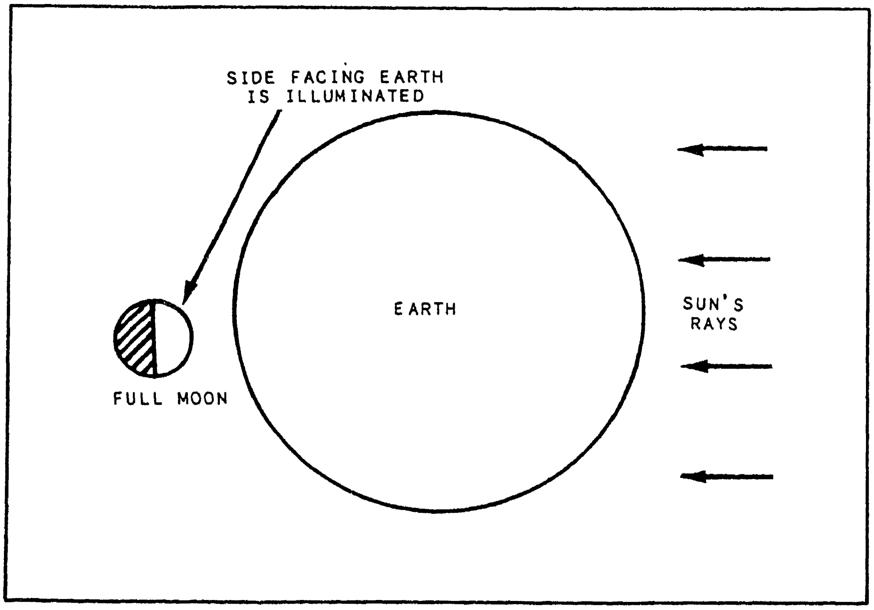


Figure 6-8-2.—Earth-Moon-Sun relationship during Full Moon phase.

AM/PM DATES (1989)	PHASE	NO. OF DAYS
P.M. 5 JAN — P.M. 9 JAN	NEW	4 1/2
A.M. 10 JAN — A.M. 13 JAN	1ST QTR	3 1/2
P.M. 13 JAN — A.M. 15 JAN	HALF	2
P.M. 15 JAN — A.M. 19 JAN	2ND QTR	4
P.M. 19 JAN — A.M. 24 JAN	FULL	5
P.M. 24 JAN — A.M. 28 JAN	3RD QTR	4
P.M. 28 JAN A.M. 31 JAN	HALF	3
P.M. 31 JAN — P.M. 3 FEB	4TH QTR	3 1/2
	TOTAL DAYS	29 1/2

Figure 6-8-3.—Moon phases through one complete revolution of Earth.

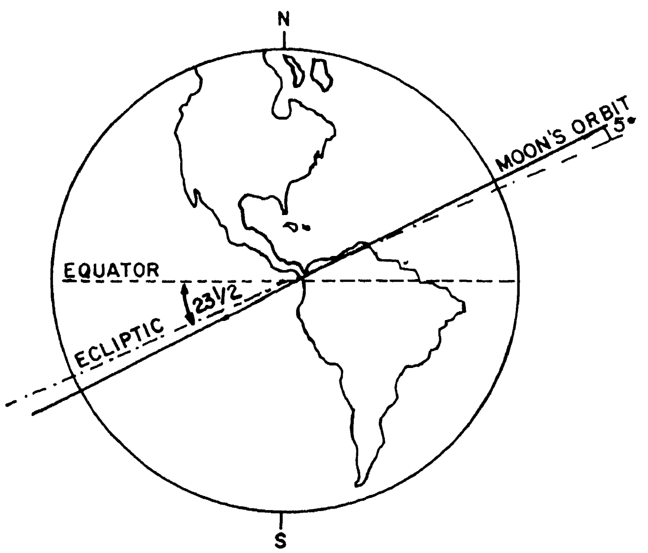


Figure 6-8-4.—Ecliptic Moon orbit.

When the Moon's orbit is above the Northern Hemisphere, moonrise is earlier in the north and later in the south. Conversely, when the orbit is above the Southern Hemisphere, moonrise is earlier in the south and later in the north. The Moon's orbital angle causes the times of moonrise and moonset to vary greatly between the extreme north and south latitudes, while at low and mid latitudes, the time differences are slight. In low and middle latitudes, moonrise and moonset occur about 50 minutes later each day.

Orbital Speed

The Moon's orbit around Earth is elliptical—not circular. See figure 6-8-5. Note that with the

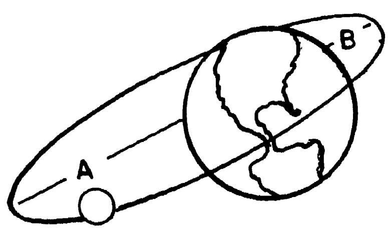


Figure 6-8-5.—Elliptic Moon orbit.

Moon in its elliptical orbit, the distance between the Moon and Earth varies. It is this difference in distance that controls the Moon's orbital speed. When the distance between the Moon and Earth decreases (B), the Moon orbits at a faster rate of speed; and when the distance increases (A), it orbits at a slower rate of speed.

The point in the Moon's orbit that is closest to Earth is known as perigee, and the point farthest away is known as apogee. At perigee, the Moon is traveling at its fastest rate of speed. At apogee, it is traveling at its slowest rate of speed. Figure 6-8-6 illustrates the distance traveled in 1 day at apogee and perigee. The distance between A and B is greater than the distance between A′ and B′, because of the Moon's faster orbital speed at this point in its orbit (perigee).

Because of the Moon's faster orbital speed at perigee, moonrise when the Moon is at point B occurs more than 50 minutes later than when the Moon is at point A. Remember, at low and mid latitudes, the Moon rises APPROXIMATELY 50 minutes later each day. At point B′, moonrise occurs less than 50 minutes later than at point A′.

Learning Objective: Identify the source providing specific times of moonrise and moonset.

AIR ALMANAC

Tables and figures in *Air Almanac* are used to obtain specific times of moonrise and moonset. The Almanac contains Moonrise and Moonset tables, a table for interpolating moonrise and moonset for longitude, and the Conversion of Arc to Time table.

Moonrise and Moonset Tables

The moonrise and moonset tables are found in the upper right corner of the daily pages of *Air Almanac*. See table 6-8-1. Note that the daily pages are either A.M. or P.M. The moonrise table appears on the A.M. pages, while the Moonset table appears on the P.M. pages. Moonrise and moonset are formulated in three columns.

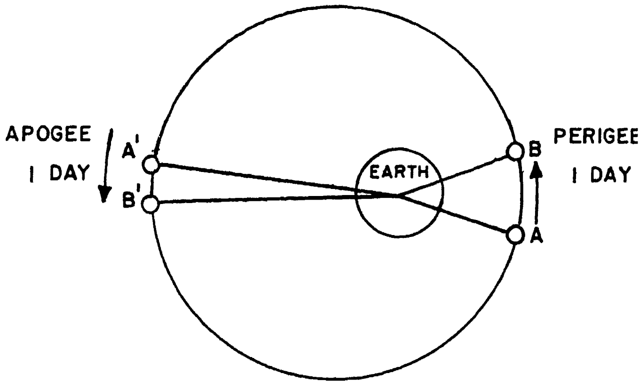


Figure 6-8-6.—Variation in Moon's orbital speed at apogee and perigee.

LATITUDE COLUMN.—Latitudes between 72 °N and 60 °S are listed vertically in the column labeled Lat. Note that the latitude increments vary. Between 72 °N and 50 °N, the increments are 2 degrees; while between 50 °N and 30 °N, the increments are 5 degrees, etc.

MOONRISE AND MOONSET COLUMNS.—The times of moonrise and moonset are listed in the Moonrise/Moonset columns. The times are listed in hours (h) and minutes (m) GMT. These times are also Local Mean Time (LMT). A time taken from this table applies to each standard longitude meridian around Earth. The standard meridians occur every 15 degrees on either side of the Prime Meridian (0 °).

Interpolation of the time may be necessary if the latitude of the location for which you are computing moonrise and moonset falls between two of the latitudes listed in the Lat. column. For example, if you are computing moonrise and moonset for 37 °N, you will find that 37 ° is NOT listed in the Lat. column. Therefore, the time of moonrise and moonset must be interpolated using the latitudes closest to 37 °N in the Lat. column (35 °N and 40 °N). Refer to lesson 7 if you need to refresh your memory on interpolating time.

Table 6-8-1.—Daily Page From 1989 Edition of Air Almanac

(DAY 213) GREENWICH P. M. 1990 AUGUST 1 (WEDNESDAY)

UT (GMT) h m	☉ SUN GHA ° ′	SUN Dec ° ′	ARIES GHA ♈ ° ′	VENUS −3.9 GHA ° ′	VENUS Dec ° ′	MARS 0.0 GHA ° ′	MARS Dec ° ′	SATURN 0.1 GHA ° ′	SATURN Dec ° ′	☉ MOON GHA ° ′	MOON Dec ° ′
12 00	358 25.1	N18 00.7	129 50.2	23 41	N22 25	88 42	N13 49	197 25	S21 48	241 12	S26 27
10	0 55.1	00.6	132 20.7	26 11		91 12		199 56		243 37	27
20	3 25.1	00.5	134 51.1	28 41		93 42		202 26		246 02	28
30	5 55.1	00.4	137 21.5	31 11		96 12		204 56		248 26	28
40	8 25.1	00.3	139 51.9	33 41		98 42		207 27		250 51	28
50	10 55.1	00.2	142 22.3	36 10		101 12		209 57		253 16	29
13 00	13 25.1	N18 00.1	144 52.7	38 40	N22 25	103 43	N13 49	212 28	S21 48	255 41	S26 29
10	15 55.1	18 00.0	147 23.1	41 10		106 13		214 58		258 06	30
20	18 25.1	17 59.9	149 53.5	43 40		108 43		217 29		260 31	30
30	20 55.1	59.8	152 23.9	46 10		111 13		219 59		262 56	31
40	23 25.1	59.7	154 54.4	48 40		113 43		222 29		265 21	31
50	25 55.2	59.6	157 24.8	51 10		116 13		225 00		267 46	32
14 00	28 25.2	N17 59.5	159 55.2	53 39	N22 25	118 44	N13 50	227 30	S21 48	270 10	S26 32
10	30 55.2	59.4	162 25.6	56 09		121 14		230 01		272 35	32
20	33 25.2	59.3	164 56.0	58 39		123 44		232 31		275 00	33
30	35 55.2	59.2	167 26.4	61 09		126 14		235 02		277 25	33
40	38 25.2	59.1	169 56.8	63 39		128 44		237 32		279 50	34
50	40 55.2	58.9	172 27.2	66 09		131 14		240 03		282 15	34
15 00	43 25.2	N17 58.8	174 57.6	68 39	N22 24	133 44	N13 50	242 33	S21 48	284 40	S26 34
10	45 55.2	58.7	177 28.0	71 09		136 15		245 04		287 05	35
20	48 25.2	58.6	179 58.5	73 38		138 45		247 34		289 29	35
30	50 55.2	58.5	182 28.9	76 08		141 15		250 04		291 54	36
40	53 25.2	58.4	184 59.3	78 38		143 45		252 35		294 19	36
50	55 55.2	58.3	187 29.7	81 08		146 15		255 05		296 44	36
16 00	58 25.2	N17 58.2	190 00.1	83 38	N22 24	148 45	N13 51	257 36	S21 48	299 09	S26 37
10	60 55.2	58.1	192 30.5	86 08		151 16		260 06		301 34	37
20	63 25.2	58.0	195 00.9	88 38		153 46		262 37		303 59	38
30	65 55.3	57.9	197 31.3	91 07		156 16		265 07		306 24	38
40	68 25.3	57.8	200 01.7	93 37		158 46		267 37		308 48	38
50	70 55.3	57.7	202 32.2	96 07		161 16		270 08		311 13	39
17 00	73 25.3	N17 57.6	205 02.6	98 37	N22 24	163 46	N13 51	272 38	S21 48	313 38	S26 39
10	75 55.3	57.5	207 33.0	101 07		166 16		275 09		316 03	39
20	78 25.3	57.4	210 03.4	103 37		168 47		277 39		318 28	40
30	80 55.3	57.3	212 33.8	106 07		171 17		280 10		320 53	40
40	83 25.3	57.2	215 04.2	108 36		173 47		282 40		323 18	40
50	85 55.3	57.1	217 34.6	111 06		176 17		285 11		325 42	41
18 00	88 25.3	N17 56.9	220 05.0	113 36	N22 24	178 47	N13 52	287 41	S21 48	328 07	S26 41
10	90 55.3	56.8	222 35.4	116 06		181 17		290 11		330 32	42
20	93 25.3	56.7	225 05.9	118 36		183 48		292 42		332 57	42
30	95 55.3	56.6	227 36.3	121 06		186 18		295 12		335 22	42
40	98 25.3	56.5	230 06.7	123 36		188 48		297 43		337 47	43
50	100 55.3	56.4	232 37.1	126 05		191 18		300 13		340 12	43
19 00	103 25.4	N17 56.3	235 07.5	128 35	N22 23	193 48	N13 52	302 44	S21 48	342 36	S26 43
10	105 55.4	56.2	237 37.9	131 05		196 18		305 14		345 01	43
20	108 25.4	56.1	240 08.3	133 35		198 48		307 44		347 26	44
30	110 55.4	56.0	242 38.7	136 05		201 19		310 15		349 51	44
40	113 25.4	55.9	245 09.1	138 35		203 49		312 45		352 16	44
50	115 55.4	55.8	247 39.5	141 05		206 19		315 16		354 41	45
20 00	118 25.4	N17 55.7	250 10.0	143 35	N22 23	208 49	N13 52	317 46	S21 48	357 06	S26 45
10	120 55.4	55.6	252 40.4	146 04		211 19		320 17		359 30	45
20	123 25.4	55.5	255 10.8	148 34		213 49		322 47		1 55	46
30	125 55.4	55.4	257 41.2	151 04		216 20		325 18		4 20	46
40	128 25.4	55.3	260 11.6	153 34		218 50		327 48		6 45	46
50	130 55.4	55.2	262 42.0	156 04		221 20		330 18		9 10	46
21 00	133 25.4	N17 55.0	265 12.4	158 34	N22 23	223 50	N13 53	332 49	S21 48	11 35	S26 47
10	135 55.4	54.9	267 42.8	161 04		226 20		335 19		13 59	47
20	138 25.4	54.8	270 13.2	163 33		228 50		337 50		16 24	47
30	140 55.5	54.7	272 43.7	166 03		231 20		340 20		18 49	48
40	143 25.5	54.6	275 14.1	168 33		233 51		342 51		21 14	48
50	145 55.5	54.5	277 44.5	171 03		236 21		345 21		23 39	48
22 00	148 25.5	N17 54.4	280 14.9	173 33	N22 23	238 51	N13 53	347 52	S21 48	26 04	S26 48
10	150 55.5	54.3	282 45.3	176 03		241 21		350 22		28 29	49
20	153 25.5	54.2	285 15.7	178 33		243 51		352 52		30 53	49
30	155 55.5	54.1	287 46.1	181 03		246 21		355 23		33 18	49
40	158 25.5	54.0	290 16.5	183 32		248 52		357 53		35 43	49
50	160 55.5	53.9	292 46.9	186 02		251 22		0 24		38 08	50
23 00	163 25.5	N17 53.8	295 17.4	188 32	N22 23	253 52	N13 54	2 54	S21 48	40 33	S26 50
10	165 55.5	53.7	297 47.8	191 02		256 22		5 25		42 58	50
20	168 25.5	53.6	300 18.2	193 32		258 52		7 55		45 22	50
30	170 55.5	53.5	302 48.6	196 02		261 22		10 25		47 47	50
40	173 25.5	53.4	305 19.0	198 32		263 53		12 56		50 12	51
50	175 55.6	53.2	307 49.4	201 02		266 23		15 26		52 37	51
Rate	15 00.0	S0 00.6		14 59.2	S0 00.2	15 00.9	N0 00.5	15 02.6	0 00.0	14 29.2	S0 02.1°

Lat. °	Moonset h m	Diff. m
N 72	■	■
70	■	■
68	■	■
66	■	■
64	■	■
62	21 25	+17
60	22 10	20
58	22 40	22
56	23 02	22
54	23 21	23
52	23 37	24
50	23 50	24
45	24 18	25
40	24 40	25
35	00 12	22
30	00 27	23
20	00 52	23
10	01 13	24
0	01 34	25
10	01 54	26
20	02 16	26
30	02 41	28
35	02 56	28
40	03 13	29
45	03 34	30
50	04 00	31
52	04 13	32
54	04 28	32
56	04 45	33
58	05 06	34
S 60	05 33	+37

Moon's P in A

Alt °	Cor ′	Alt °	Cor ′
0		57	
	54		29
10		58	
	53		28
15		59	
	52		27
18		60	
	51		26
21		62	
	50		25
24		63	
	49		24
26		64	
	48		23
29		65	
	47		22
31		66	
	46		21
33		67	
	45		20
35		68	
	44		19
36		70	
	43		18
38		71	
	42		17
40		72	
	41		16
41		73	
	40		15
43		74	
	39		14
44		75	
	38		13
46		76	
	37		12
47		77	
	36		11
49		78	
	35		10
50		79	
	34		
51			
	33		
53			
	32		
54			
	31		
55			
	30		
57			
	29		
58			

Sun SD 15′.8
Moon SD 15′
Age 10d

(DAY 214) GREENWICH A. M. 1990 AUGUST 2 (THURSDAY)

UT (GMT) h m	☉ SUN GHA ° ′	SUN Dec. ° ′	ARIES GHA ♈ ° ′	VENUS −3.9 GHA ° ′	VENUS Dec. ° ′	MARS 0.0 GHA ° ′	MARS Dec. ° ′	SATURN 0.1 GHA ° ′	SATURN Dec. ° ′	☉ MOON GHA ° ′	MOON Dec. ° ′
00 00	178 25.6	N17 53.1	310 19.8	203 31	N22 22	268 53	N13 54	17 57	S21 48	55 02	S26 51
10	180 55.6	53.0	312 50.2	206 01		271 23		20 27		57 27	51
20	183 25.6	52.9	315 20.6	208 31		273 53		22 58		59 51	52
30	185 55.6	52.8	317 51.0	211 01		276 23		25 28		62 16	52
40	188 25.6	52.7	320 21.5	213 31		278 53		27 59		64 41	52
50	190 55.6	52.6	322 51.9	216 01		281 24		30 29		67 06	52
01 00	193 25.6	N17 52.5	325 22.3	218 31	N22 22	283 54	N13 55	32 59	S21 48	69 31	S26 52
10	195 55.6	52.4	327 52.7	221 00		286 24		35 30		71 55	52
20	198 25.6	52.3	330 23.1	223 30		288 54		38 00		74 20	53
30	200 55.6	52.2	332 53.5	226 00		291 24		40 31		76 45	53
40	203 25.6	52.1	335 23.9	228 30		293 54		43 01		79 10	53
50	205 55.6	52.0	337 54.3	231 00		296 25		45 32		81 35	53
02 00	208 25.6	N17 51.9	340 24.7	233 30	N22 22	298 55	N13 55	48 02	S21 48	84 00	S26 53
10	210 55.6	51.8	342 55.2	236 00		301 25		50 33		86 24	54
20	213 25.7	51.7	345 25.6	238 29		303 55		53 03		88 49	54
30	215 55.7	51.6	347 56.0	240 59		306 25		55 33		91 14	54
40	218 25.7	51.4	350 26.4	243 29		308 55		58 04		93 39	54
50	220 55.7	51.3	352 56.8	245 59		311 26		60 34		96 04	54
03 00	223 25.7	N17 51.2	355 27.2	248 29	N22 22	313 56	N13 56	63 05	S21 48	98 28	S26 54
10	225 55.7	51.1	357 57.6	250 59		316 26		65 35		100 53	55
20	228 25.7	51.0	0 28.0	253 29		318 56		68 06		103 18	55
30	230 55.7	50.9	2 58.4	255 59		321 26		70 36		105 43	55
40	233 25.7	50.8	5 28.9	258 28		323 56		73 06		108 08	55
50	235 55.7	50.7	7 59.3	260 58		326 26		75 37		110 33	55
04 00	238 25.7	N17 50.6	10 29.7	263 28	N22 21	328 57	N13 56	78 07	S21 48	112 57	S26 55
10	240 55.7	50.5	13 00.1	265 58		331 27		80 38		115 22	55
20	243 25.7	50.4	15 30.5	268 28		333 57		83 08		117 47	55
30	245 55.7	50.3	18 00.9	270 58		336 27		85 39		120 12	56
40	248 25.8	50.2	20 31.3	273 28		338 57		88 09		122 37	56
50	250 55.8	50.1	23 01.7	275 58		341 27		90 40		125 01	56
05 00	253 25.8	N17 50.0	25 32.1	278 27	N22 21	343 58	N13 57	93 10	S21 48	127 26	S26 56
10	255 55.8	49.9	28 02.5	280 57		346 28		95 41		129 51	56
20	258 25.8	49.7	30 33.0	283 27		348 58		98 11		132 16	56
30	260 55.8	49.6	33 03.4	285 57		351 28		100 41		134 41	56
40	263 25.8	49.5	35 33.8	288 27		353 58		103 12		137 05	56
50	265 55.8	49.4	38 04.2	290 57		356 28		105 42		139 30	56
06 00	268 25.8	N17 49.3	40 34.6	293 27	N22 21	358 58	N13 57	108 13	S21 48	141 55	S26 56
10	270 55.8	49.2	43 05.0	295 56		1 29		110 43		144 20	56
20	273 25.8	49.1	45 35.4	298 26		3 59		113 14		146 45	56
30	275 55.8	49.0	48 05.8	300 56		6 29		115 44		149 09	57
40	278 25.8	48.9	50 36.2	303 26		8 59		118 14		151 34	57
50	280 55.8	48.8	53 06.7	305 56		11 29		120 45		153 59	57
07 00	283 25.9	N17 48.7	55 37.1	308 26	N22 21	13 59	N13 58	123 15	S21 48	156 24	S26 57
10	285 55.9	48.6	58 07.5	310 56		16 30		125 46		158 49	57
20	288 25.9	48.5	60 37.9	313 25		19 00		128 16		161 13	57
30	290 55.9	48.4	63 08.3	315 55		21 30		130 47		163 38	57
40	293 25.9	48.3	65 38.7	318 25		24 00		133 17		166 03	57
50	295 55.9	48.2	68 09.1	320 55		26 30		135 48		168 28	57
08 00	298 25.9	N17 48.0	70 39.5	323 25	N22 20	29 00	N13 58	138 18	S21 48	170 53	S26 57
10	300 55.9	47.9	73 09.9	325 55		31 31		140 48		173 17	57
20	303 25.9	47.8	75 40.4	328 25		34 01		143 19		175 42	57
30	305 55.9	47.7	78 10.8	330 55		36 31		145 49		178 06	57
40	308 25.9	47.6	80 41.2	333 24		39 01		148 20		180 32	57
50	310 55.9	47.5	83 11.6	335 54		41 31		150 50		182 57	57
09 00	313 25.9	N17 47.4	85 42.0	338 24	N22 20	44 01	N13 59	153 21	S21 48	185 21	S26 57
10	315 55.9	47.3	88 12.4	340 54		46 31		155 51		187 46	57
20	318 26.0	47.2	90 42.8	343 24		49 02		158 22		190 11	57
30	320 56.0	47.1	93 13.2	345 54		51 32		160 52		192 36	57
40	323 26.0	47.0	95 43.6	348 24		54 02		163 22		195 01	57
50	325 56.0	46.9	98 14.0	350 54		56 32		165 53		197 25	57
10 00	328 26.0	N17 46.8	100 44.5	353 23	N22 20	59 02	N13 59	168 23	S21 48	199 50	S26 57
10	330 56.0	46.7	103 14.9	355 53		61 32		170 54		202 15	57
20	333 26.0	46.6	105 45.3	358 23		64 03		173 24		204 40	57
30	335 56.0	46.4	108 15.7	0 53		66 33		175 55		207 05	57
40	338 26.0	46.3	110 46.1	3 23		69 03		178 25		209 29	57
50	340 56.0	46.2	113 16.5	5 53		71 33		180 55		211 54	57
11 00	343 26.0	N17 46.1	115 46.9	8 23	N22 20	74 03	N14 00	183 26	S21 48	214 19	S26 57
10	345 56.0	46.0	118 17.3	10 52		76 33		185 56		216 44	57
20	348 26.0	45.9	120 47.7	13 22		79 03		188 27		219 08	57
30	350 56.1	45.8	123 18.2	15 52		81 34		190 57		221 33	57
40	353 26.1	45.7	125 48.6	18 22		84 04		193 28		223 58	57
50	355 56.1	45.6	128 19.0	20 52		86 34		195 58		226 23	57
Rate	15 00.0	S0 00.6		14 59.2	S0 00.2	15 00.9	N0 00.5	15 02.6	0 00.0	14 28.8	S0 00.5°

Lat. °	Moonrise h m	Diff. m
N 72	■	■
70	■	■
68	■	■
66	■	■
64	■	■
62	19 53	+19
60	19 07	22
58	18 37	23
56	18 14	23
54	17 55	24
52	17 39	24
50	17 26	24
45	16 58	24
40	16 36	25
35	16 18	25
30	16 02	26
20	15 35	26
10	15 12	26
0	14 51	26
10	14 30	26
20	14 07	26
30	13 41	26
35	13 25	26
40	13 07	26
45	12 45	26
50	12 17	26
52	12 03	26
54	11 48	26
56	11 29	26
58	11 07	26
S 60	10 37	+26

Moon's P in A.

Alt °	Cor ′	Alt °	Cor ′
0		57	
	54		29
10		58	
	53		28
15		59	
	52		27
19		60	
	51		26
22		62	
	50		25
24		63	
	49		24
27		64	
	48		23
29		65	
	47		22
31		66	
	46		21
33		67	
	45		20
35		69	
	44		19
37		70	
	43		18
38		71	
	42		17
40		72	
	41		16
42		73	
	40		15
43		74	
	39		14
45		75	
	38		13
46		76	
	37		12
47		77	
	36		11
49		78	
	35		10
50		79	
	34		
52			
	33		
53			
	32		
54			
	31		
55			
	30		
57			
	29		
58			

Sun SD 15′.8
Moon SD 15′
Age 11d

Two symbols may or may not appear in this column. They are ▭ and ■. The symbol ▭ means the moon is continuously above the horizon, while the symbol ■ means the moon is continuously below the horizon.

ONE-HALF THE DAILY TIME DIFFERENCE COLUMN.—One-half of the daily time difference between moonrise and moonset for each latitude at 90°E or 90°W is listed in the Diff. column. The time difference is in minutes (m). Plus (+) and minus (−) signs are assigned to the time differences. A + is applied to west longitudes and a − is applied to east longitudes. The asterisk (*) signifies that the one-half daily time differences could not be interpolated.

Interpolation of Moonrise, Moonset for Longitude Table

The Interpolation of Moonrise, Moonset for Longitude table (table 6-8-2) is used to find the time correction pertaining to longitude. This table consists of three sets of longitude and time difference figures.

The longitudes, in whole degrees, are listed vertically to the left of each set. The longitude increments differ in each set. In the top set, the longitudes are listed for every 20 degrees; in the middle set, they are 15 degrees; and in the bottom set, they are 10 degrees.

The time differences, in 5-minute increments, extend across the top of each set. The top set covers time differences from 5 to 30 minutes, the middle set covers from 35 to 60 minutes, and the bottom set covers from 65 to 90 minutes. The time difference determines which set of longitudes you will use.

Use the time difference column that is closest to the time difference obtained from the Moonrise and Moonset table. DO NOT INTERPOLATE. For example, let's say the time difference is 24. Using table 6-8-2, find the column heading closest to 24, which is 25. The time correction is taken from this column. Next, find the longitude in the Longitude column. Remember, use the closest longitude. DO NOT INTERPOLATE. The time correction for longitude is found where the time difference and longitude intersect.

Conversion of Arc to Time Table

The Conversion of Arc to Time table was covered in Unit 6, Lesson 7; therefore, I will not cover it again here.

Table 6-8-2.—Interpolation of Moonrise, Moonset for Longitude

Longitude	Add if longitude is west, subtract if longitude is east					
	Diff.*					
	05	10	15	20	25	30
°	m	m	m	m	m	m
0	00	00	00	00	00	00
20	01	01	02	02	03	03
40	01	02	03	04	06	07
60	02	03	05	07	09	10
80	02	04	07	09	11	13
100	03	06	08	11	14	17
120	03	07	10	13	17	20
140	04	08	12	16	19	23
160	04	09	13	18	22	27
180	05	10	15	20	25	30
	Diff.*					
Longitude	35	40	45	50	55	60
°	m	m	m	m	m	m
0	00	00	00	00	00	00
15	03	03	04	04	05	05
30	06	07	08	08	09	10
45	09	10	11	12	14	15
60	12	13	15	17	18	20
75	15	17	19	21	23	25
90	18	20	22	25	28	30
105	20	23	26	29	32	35
120	23	27	30	33	37	40
135	26	30	34	38	41	45
150	29	33	38	42	46	50
165	32	37	41	46	50	55
180	35	40	45	50	55	60
	Diff.*					
Longitude	65	70	75	80	85	90
°	m	m	m	m	m	m
0	00	00	00	00	00	00
10	04	04	04	04	05	05
20	07	08	08	09	09	10
30	11	12	12	13	14	15
40	14	16	17	18	19	20
50	18	19	21	22	24	25
60	22	23	25	27	28	30
70	25	27	29	31	33	35
80	29	31	33	36	38	40
90	32	35	38	40	42	45
100	36	39	42	44	47	50
110	40	43	46	49	52	55
120	43	47	50	53	57	60
130	47	51	54	58	61	65
140	51	54	58	62	66	70
150	54	58	62	67	71	75
160	58	62	67	71	76	80
170	61	66	71	76	80	85
180	65	70	75	80	85	90

*When negative, subtract correction if longitude is west, a add if east.

Learning Objective: Identify the steps used to compute moonrise and moonset from *Air Almanac*.

MOONRISE AND MOONSET COMPUTATIONS

To compute the time of moonrise and moonset on a particular day of the year at a specific location, follow these steps:

Step 1. Locate the day in the daily pages of *Air Almanac*.

Step 2. Enter the Moonrise and Moonset table with the latitude of the location for which you are determining moonrise and moonset and read the time and time differential. Interpolate when necessary.

Step 3. Determine the time correction from the Interpolation of Moonrise, Moonset for Longitude table.

Step 4. Apply the time correction obtained in step 3 to the time obtained in step 2. This is the time of moonrise/moonset LMT.

Step 5. Convert LMT to Local Standard Time (LST) using the Conversion of Arc to Time table.

Example: Compute moonrise on 4 August 1989, at 30°21'N 87°19'W.

Step 1. Use the daily page for 4 August 1989 (table 6-8-1).

Step 2. Determine the time and time differential at 30°21'N from the Moonrise table. 30°21'N rounds off to 30°N; 30°N = 07:50 LMT; and the time difference equals 28 minutes.

Step 3. Determine the time correction for longitude 87°19'W. Use table 6-8-2. The longitude in the table closest to 87°19'W is 80, and the time difference closest to 28 is 30. The time correction is 11 minutes.

Step 4. Add 11 minutes to 07:50 LMT (07:50 + :11 = 07:61 = 08:01 LMT).

Step 5. Convert 08:01 LMT to LST using table 6-7-2.

PRACTICAL TRAINING EXERCISE

Using the current *Air Almanac*, compute the times of moonrise and moonset for the following locations:

1. Your station, tomorrow.

2. Lajes A.B., Azores, (38°46'W, 27°06'W) on 25 March.

3. Jodhpur, India, (26°16'N, 73°03'W) on 29 July.

4. Vladivostok, U.S.S.R., (43°07'N, 131°54'E) on 12 September.

Have your immediate supervisor or leading chief answer any questions you may have, and then have one of them check your computations.

Learning Objective: Relate the age of the Moon, in days, to the percent illumination available.

LUNAR ILLUMINATION

Many Department of Defense units are currently using low-light-level enhancing systems to identify and track targets at night. These systems range from "starlight" scopes, commonly used aboard ships, to night vision goggles (NVGs), used by both fixed- and rotary-wing-aircraft pilots. You may be asked to provide illumination data in addition to Moonrise and Moonset times. With your Tactical Environmental Software System (TESS) library and your desk-top computer, you may calculate lunar illumination quickly and accurately. You may find on occasion that the computer isn't available; so in this section, we will give you an alternative method for estimating the percent illumination from information presented in *Air Almanac*, as well as in *Nautical Almanac*.

At the lower right corner of each page of daily predictions in *Air Almanac*, you will find a small block (see table 6-8-1). In this block, the age of the Moon is given in days, such as 3d for the 3d day of the lunar cycle. These values will range from 0 to 29. Since the lunar cycle is 29 1/2 days,

the 0 day is used every other month or so to balance things out.

The same information is available in *Nautical Almanac* in the lower right corner of each page of the daily predictions.

Enter table 6-8-3 with the age of the Moon to find an estimate of the illumination. The percent illumination value is the portion of the Moon that is illuminated. It is not a comparison of the normal amount of light or illumination available during the day.

Table 6-8-3.—Percent Illumination of the Moon

AGE	PERCENT ILLUMINATION	AGE	PERCENT ILLUMINATION	AGE	PERCENT ILLUMINATION
0	00 ±0%	10	77 ±5%	20	72 ±5%
1	01 ±1%	11	85 ±4%	21	62 ±5%
2	04 ±2%	12	92 ±3%	22	52 ±6%
3	10 ±3%	13	97 ±3%	23	43 ±5%
4	18 ±4%	14	99 ±1%	24	31 ±5%
5	26 ±4%	15	100 ±0%	25	22 ±4%
6	36 ±5%	16	98 ±1%	26	14 ±4%
7	46 ±5%	17	95 ±2%	27	07 ±2%
8	57 ±6%	18	89 ±3%	28	03 ±1%
9	67 ±5%	19	81 ±4%	29	00 ±0%

NOTE: The variance listed after each illumination value takes into account the rounding off of the Moon's age to the nearest day in the daily predictions in *Nautical Almanac* and *Air Almanac*.

Between the time of Moonrise and Moonset, the illumination will increase by one-half the variance when the Moon is waxing, and decrease by one-half the variance when the Moon is waning.

UNIT 6—LESSON 9

RADIOLOGICAL FALLOUT

OVERVIEW	OUTLINE
Recognize how weapon yield and burst type affect radiological fallout (RADFO).	Nuclear burst
Diagram the zones of most hazardous fallout using the information contained in the Basic Wind Data Message.	Basic Wind Data Message
Diagram the zones of most hazardous fallout using the information contained in the Effective Downwind Message.	Effective Downwind Message
Compute effective downwind directions and speeds using standard-pressure-level winds.	Computation of effective fallout winds using standard-pressure-level winds

RADIOLOGICAL FALLOUT

The RADiological FallOut (RADFO) from a nuclear weapon can affect a widespread area around a blast site. If you are ever involved in an operation where the use of nuclear weapons is considered, the operational commander will need to know the potentially hazardous areas due to RADFO. This information is used in making decisions regarding evasive action, evacuation, radiological countermeasures, and so forth.

Learning Objective: Recognize how weapon yield and burst type affect RADFO.

NUCLEAR BURSTS

Nuclear bursts produce clouds that contain radioactive matter. This matter eventually returns to Earth's surface as RADFO. The height to which these clouds rise is dependent principally upon the yield of the nuclear weapon, and the type of burst.

Weapon Yield

Weapon yield determines the energy released in a nuclear blast and the height to which radioactive material will ascend into the atmosphere. For example, if a 1-kiloton (kt) nuclear burst occurs at or near the surface, the nuclear cloud that forms will rise to a height of approximately 3,800 meters, or 12,500 feet. A 1-kt nuclear burst is equal to an explosion of 1,000 tons of TNT.

Nuclear bursts are divided into seven yield (pre-selected) groups for use with certain RADFO messages and computations. The weapon yield breakdown is as follows:

ALPHA	2 kt (kiloton) or less
BRAVO	>2 kt to 5 kt
CHARLIE	>5 kt to 30 kt
DELTA	>30 kt to 100 kt
ECHO	>100 kt to 300 kt
FOXTROT	>300 kt to 1 Mt (megaton)
GOLF	>1 Mt to 3 Mt

Types of Nuclear Bursts

There are four types of nuclear bursts: high-air, low-air, surface, and subsurface.

HIGH-AIR BURST.—A high-air burst does NOT damage targets or cause casualties on the surface. Neither induced-radiation nor fallout are of tactical significance there. High-air bursts are designed to disrupt communications.

LOW-AIR BURST.—A low-air burst produces damage or casualties at the surface; however, the burst is at such a height as to produce minimal fallout. In a low-air burst, only neutron radiation occurs. Neutron-induced radiation is relatively limited in area, and changes in tactics can normally be made to ensure that it does not grossly interfere with operations.

SURFACE BURST.—Both neutron-induced radiation and fallout result from a surface or near-surface burst. The fallout pattern usually overlaps and overshadows the entire induced-radiation pattern. RADFO messages are based on a surface or near-surface burst.

SUBSURFACE BURST.—A subsurface burst produces both induced radiation and fallout on the ground.

Radiological Fallout (RADFO)

Radiological fallout from large surface bursts creates a major operational problem. Potentially, it may extend to far greater distances than the immediate blast area and may cause more casualties than any other nuclear weapon effect.

Another problem with fallout is that it may exist for a considerable time after detonation, especially overland. Overland, fallout remains a hazard until the radioactive material decays. Fallout at sea is not as great a factor as it is overland, because the ocean absorbs fallout and acts as a shield against radioactive material. Ships can avoid RADFO by moving beyond the fallout zones.

Areas of hazardous RADFO are determined and diagramed using data based on weapon yield and the atmospheric winds in the vicinity of the blast. The winds determine the direction in which and the speed at which RADFO will travel.

Two types of RADFO messages are used in diagraming fallout areas. They are the Basic Wind Data Message and the Effective Fallout Data Message. In the absence of either of these messages, Aerographer's Mates must work from raw wind-data taken from upper-air reports.

Learning Objective: Diagram the zones of the most hazardous fallout using the information contained in the Basic Wind Data Message.

BASIC WIND DATA MESSAGE

The Basic Wind Data Message provides mean winds between the surface and 30,000 meters (100,000 feet) in 2,000-meter increments. See figure 6-9-1. Note that each layer is designated by a code figure. For example, the surface-to-2,000-meter layer is encoded as 2; the 3,000-to-4,000-meter layer as 4, and so forth.

The wind direction (ddd) and speed (fff) for each layer are entered using six digits—three digits for direction and three digits for speed. The wind direction and speed may appear as one 6-digit group or two 3-digit groups. For example, the

GEØ (zone of validity)
Z 140600 (time of measuring)

(layer)	(degrees)	(km/h)
2	265	020
4	290	030
6	300	035
8	310	035
10	330	040
12	345	040
14	355	035
16	005	030
18	015	025
20	020	015
22	020	020
24	025	020
26	025	020
28	030	020
30	030	025

Figure 6-9-1.—Example of a basic wind data message.

surface-to-2,000-meter layer may appear as follows:

Code figure	Wind Dir/Speed
2	280030
or	
2	280 030

Wind direction for each layer is the direction from which the wind is blowing, and it is entered to the nearest 5 degrees. Mean wind speeds are entered in kilometers per hour or in knots. *Kilometers per hour* is used in transmissions to shore-base units, and the message is titled BASIC WIND DATA MESSAGE. *Knots* is used in transmissions to ships, and the message is titled NAV BASIC WIND DATA MESSAGE.

Wind Vector Plots

Mean wind information is used to construct vector plots, which are used to determine the zones of the most hazardous radioactive fallout. *Wind direction* is converted into downwind directions, and wind speed is converted into vector lengths.

To plot wind vectors, first add 180 degrees to or subtract it from the wind direction given for each layer. This gives you vector direction. *Vector direction* is the downwind direction, or the direction in which the fallout will travel. For example, a wind of 270° produces a downwind direction of 090°.

Next, determine vector length. Convert mean wind speed for each layer into vector length, using tables 6-9-1 (A or B), 6-9-2 (A or B), or 6-9-3 (A or B). Each table is based on a map scale (1:50,000, 1:100,000, or 1:250,000) and a unit of measurement for wind speed (kilometers per hour or knots). REMEMBER: IF THE RADFO MESSAGE BEGINS WITH NAV, YOU MUST USE THE VECTOR LENGTH TABLES REFERRING TO KNOTS. Vector length is in centimeters. For example, if the mean speed in a layer is 20 knots and you are working with a map with a scale of 1:100,000, vector length will be 25.2 centimeters.

The next step is to plot the wind vectors. First, label ground zero GZ and grid north GN. GZ is the location of the blast. Second, from GZ, draw the vector for the first layer (surface to 2,000 meters) and label the end of the vector with a 2. From the end of the first-layer vector, draw the second-layer vector (2,000-to-4,000-meter layer) and label the end point with a 4. Plot all of the remaining vectors in the same manner. The final result of plotting wind vectors will be a single vector plot, as shown in figure 6-9-2.

Determining Effective Fallout Wind

To determine the effective fallout wind and the hazardous fallout zones, in addition to the wind vector plot, you must determine the height of the top and bottom of the nuclear cloud and the 2/3 stem height. This information is taken

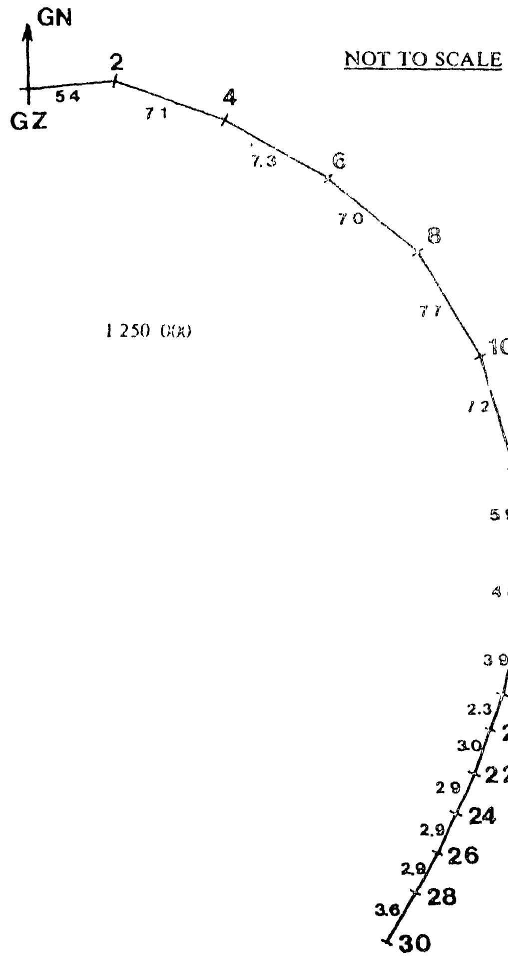


Figure 6-9-2.—Wind vector plot.

Table 6-9-1(A).—Vector Lengths in Centimeters for Map Scale 1:50,000 and Wind Speed in Knots

1:50,000 knots

WIND SPEED knots	ALTITUDE LAYERS (thousands of meters)											
	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-22	22-30	>30
5	12.6	11.0	9.6	9.4	9.0	8.4	7.8	7.4	7.2	7.0	6.6	6.4
10	25.2	21.8	19.2	18.6	17.8	16.6	15.6	14.8	14.4	14.0	13.2	12.6
15	37.8	32.8	28.8	28.0	26.8	25.0	23.4	22.2	21.6	20.8	19.6	19.0
20	50.4	43.6	38.4	37.2	35.6	33.2	31.2	29.6	28.8	27.8	26.2	25.2
25	63.0	54.6	48.0	46.6	44.6	41.2	39.0	37.0	36.0	34.8	32.8	31.6
30	65.6	65.4	57.6	55.8	53.4	49.8	46.8	44.4	43.2	41.8	39.4	37.8

Note: Above 18,000 meters, altitude layers for plotting vector diagrams continue to be at 2,000 meter intervals. However, the map distance factors vary so little that some of the columns in the above table are combined for convenience.

Table 6-9-1(B).—Vector Lengths in Centimeters for Map Scale 1:50,000 and Wind Speed in Kilometers-per-hour

1:50,000 km/h

WIND SPEED km/h	ALTITUDE LAYERS (thousands of meters)											
	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-22	22-30	>30
5	6.8	5.8	5.2	5.0	4.8	4.4	4.2	4.0	3.8	3.8	3.6	3.4
10	13.6	11.8	10.4	10.0	9.6	9.0	8.4	8.0	7.8	7.6	7.2	6.8
15	20.4	17.6	15.6	15.0	14.4	13.4	12.6	12.0	11.6	11.2	10.8	10.2
20	27.2	23.6	20.8	20.0	19.2	18.0	16.8	16.0	15.6	15.0	14.2	13.6
25	34.0	29.4	26.0	25.2	24.0	22.4	21.0	20.0	19.4	18.8	17.8	17.0

Note: Above 18,000 meters, altitude layers for plotting vector diagrams continue to be at 2,000 meter intervals. However, the map distance factors vary so little that some of the columns in the above table are combined for convenience.

Table 6-9-2(A).—Vector Lengths in Centimeters for Map Scale 1:100,000 and Wind Speed in Knots

1:100,000 knots

WIND SPEED knots	ALTITUDE LAYERS (thousands of meters)											
	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-22	22-30	>30
5	6.3	5.5	4.8	4.7	4.5	4.2	3.9	3.7	3.6	3.5	3.3	3.2
10	12.6	10.9	9.6	9.3	8.9	8.3	7.8	7.4	7.2	7.0	6.6	6.3
15	18.9	16.4	14.4	14.0	13.4	12.5	11.7	11.1	10.8	10.4	9.8	9.5
20	25.2	21.8	19.2	18.6	17.8	16.6	15.6	14.8	14.4	13.9	13.1	12.6
25	31.5	27.3	24.0	23.3	22.3	20.6	19.5	18.5	18.0	17.4	16.4	15.8
30	37.8	32.7	28.8	27.9	26.7	24.9	23.4	22.2	21.6	20.9	19.7	18.9
35	44.1	38.2	33.6	32.6	31.2	29.1	27.3	25.9	25.2	24.3	22.9	22.1
40	50.4	43.6	38.4	37.2	35.6	33.2	31.2	29.6	28.8	27.8	26.2	25.2
45	56.7	49.1	43.2	41.9	40.1	37.4	35.1	33.3	32.4	31.3	29.5	28.4
50	63.0	54.5	48.0	46.5	44.5	41.5	39.0	37.0	36.0	34.8	32.8	31.5

Note: Above 18,000 meters, altitude layers for plotting vector diagrams continue to be at 2,000 meter intervals. However, the map distance factors vary so little that some of the columns in the above table are combined for convenience.

Table 6-9-2(B).—Vector Lengths in Centimeters for Map Scale 1:100,000 and Wind Speed in Kilometers-per-hour

1:100,000 km/h

WIND SPEED km/h	ALTITUDE LAYERS (thousands of meters)											
	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-22	22-30	>30
5	3.4	2.9	2.6	2.5	2.4	2.2	2.1	2.0	1.9	1.9	1.8	1.7
10	6.8	5.9	5.2	5.0	4.8	4.5	4.2	4.0	3.9	3.8	3.6	3.4
15	10.2	8.8	7.8	7.5	7.2	6.7	6.3	6.0	5.8	5.6	5.4	5.1
20	13.6	11.8	10.4	10.0	9.6	9.0	8.4	8.0	7.8	7.5	7.1	6.8
25	17.0	14.7	13.0	12.6	12.0	11.2	10.5	10.0	9.7	9.4	8.9	8.5
30	20.4	17.7	15.6	15.1	14.4	13.4	12.6	12.0	11.7	11.3	10.7	10.2
35	23.8	20.6	18.1	17.6	16.8	15.7	14.7	14.0	13.6	13.1	12.5	11.9
40	27.2	23.6	20.7	20.1	19.2	17.9	16.8	16.0	15.6	15.0	14.3	13.6
45	30.6	26.5	23.3	22.6	21.6	20.2	19.0	18.0	17.5	16.9	16.1	15.3
50	34.0	29.5	25.9	25.1	24.0	22.4	21.1	20.0	19.4	18.8	17.9	17.0

Note: Above 18,000 meters, altitude layers for plotting vector diagrams continue to be at 2,000 meter intervals. However, the map distance factors vary so little that some of the columns in the above table are combined for convenience.

Table 6-9-3(A).—Vector Lengths in Centimeters for Map Scale 1:250,000 and Wind Speed in Knots

1:250,000 knots

WIND SPEED knots	ALTITUDE LAYERS (thousands of meters)											
	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-22	22-30	>30
5	2.5	2.2	1.9	1.9	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.3
10	5.0	4.4	3.8	3.7	3.6	3.3	3.1	3.0	2.9	2.8	2.6	2.5
15	7.6	6.5	5.8	5.6	5.3	5.0	4.7	4.4	4.3	4.2	3.9	3.8
20	10.1	8.7	7.7	7.4	7.1	6.6	6.2	5.9	5.8	5.6	5.2	5.0
25	12.6	10.9	9.6	9.3	8.9	8.3	7.8	7.4	7.2	7.0	6.6	6.3
30	15.1	13.1	11.5	11.2	10.7	10.0	9.4	8.9	8.6	8.3	7.9	7.6
35	17.6	15.3	13.4	13.0	12.5	11.6	10.9	10.4	10.1	9.7	9.2	8.8
40	20.2	17.4	15.4	14.9	14.2	13.3	12.5	11.8	11.5	11.1	10.5	10.1
45	22.7	19.6	17.3	16.7	16.0	14.9	14.0	13.3	13.0	12.5	11.8	11.3
50	25.2	21.8	19.2	18.6	17.8	16.6	15.6	14.8	14.4	13.9	13.1	12.6
55	27.7	24.0	21.1	20.5	19.6	18.3	17.2	16.3	15.8	15.3	14.4	13.9
60	30.2	26.2	23.0	22.3	21.4	19.9	18.7	17.8	17.3	16.7	15.7	15.1
75	37.8	32.7	28.8	27.9	26.7	24.9	23.4	22.2	21.6	20.9	19.7	18.9
100	50.4	43.6	38.4	37.2	35.6	33.2	31.2	29.6	28.8	27.8	26.2	25.2

Note: Above 18,000 meters, altitude layers for plotting vector diagrams continue to be at 2,000 meter intervals. However, the map distance factors vary so little that some of the columns in the above table are combined for convenience.

Table 6-9-3(B).—Vector Lengths in Centimeters for Map Scale 1:250,000 and Wind Speed in Kilometers-per-hour

1:250,000 km/h

WIND SPEED km/h	ALTITUDE LAYERS (thousands of meters)											
	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-22	22-30	>30
5	1.4	1.2	1.0	1.0	1.0	0.9	0.8	0.8	0.8	0.8	0.7	0.7
10	2.7	2.4	2.1	2.0	1.9	1.8	1.7	1.6	1.6	1.5	1.4	1.4
15	4.1	3.5	3.1	3.0	2.9	2.7	2.5	2.4	2.3	2.3	2.1	2.0
20	5.4	4.7	4.1	4.0	3.8	3.6	3.4	3.2	3.1	3.0	2.9	2.7
25	6.8	5.9	5.2	5.0	4.8	4.5	4.2	4.0	3.9	3.8	3.6	3.4
30	8.2	7.1	6.2	6.0	5.8	5.4	5.1	4.8	4.7	4.5	4.3	4.1
35	9.5	8.2	7.3	7.0	6.7	6.3	5.9	5.6	5.4	5.3	5.0	4.8
40	10.9	9.4	8.3	8.0	7.7	7.2	6.7	6.4	6.2	6.0	5.7	5.4
45	12.2	10.6	9.3	9.0	8.6	8.1	7.6	7.2	7.0	6.8	6.4	6.1
50	13.6	11.8	10.4	10.0	9.6	9.0	8.4	8.0	7.8	7.5	7.1	6.8
55	15.0	12.9	11.4	11.0	10.6	9.9	9.3	8.8	8.6	8.3	7.9	7.5
60	16.3	14.1	12.4	12.0	11.5	10.8	10.1	9.6	9.3	9.0	8.6	8.2
75	20.4	17.7	15.5	15.1	14.4	13.4	12.6	12.0	11.7	11.3	10.7	10.2
100	27.2	23.5	20.7	20.1	19.2	17.9	16.9	16.0	15.6	15.0	14.3	13.6

Note: Above 18,000 meters, altitude layers for plotting vector diagrams continue to be at 2,000 meter intervals. However, the map distance factors vary so little that some of the columns in the above table are combined for convenience.

from the Stabilized Cloud and Stem Parameters nomogram, shown in figure 6-9-3.

To use the nomogram, you simply take a straightedge and connect the estimated or reported yield of the blast on the left with the identical figure on the right. Then, you read the cloud top- and bottom height and the 2/3 stem height along this line. Information on cloud radius and time of fall from the cloud base can also be determined from this nomogram.

EXAMPLE: From figure 6-9-3, the following parameters were determined for a 50-kt yield:

Cloud-top height	12,700 meters
Cloud-bottom height	8,300 meters
2/3 stem height	5,500 meters
Cloud radius	5 kilometers
Time of fall	2.35 hours

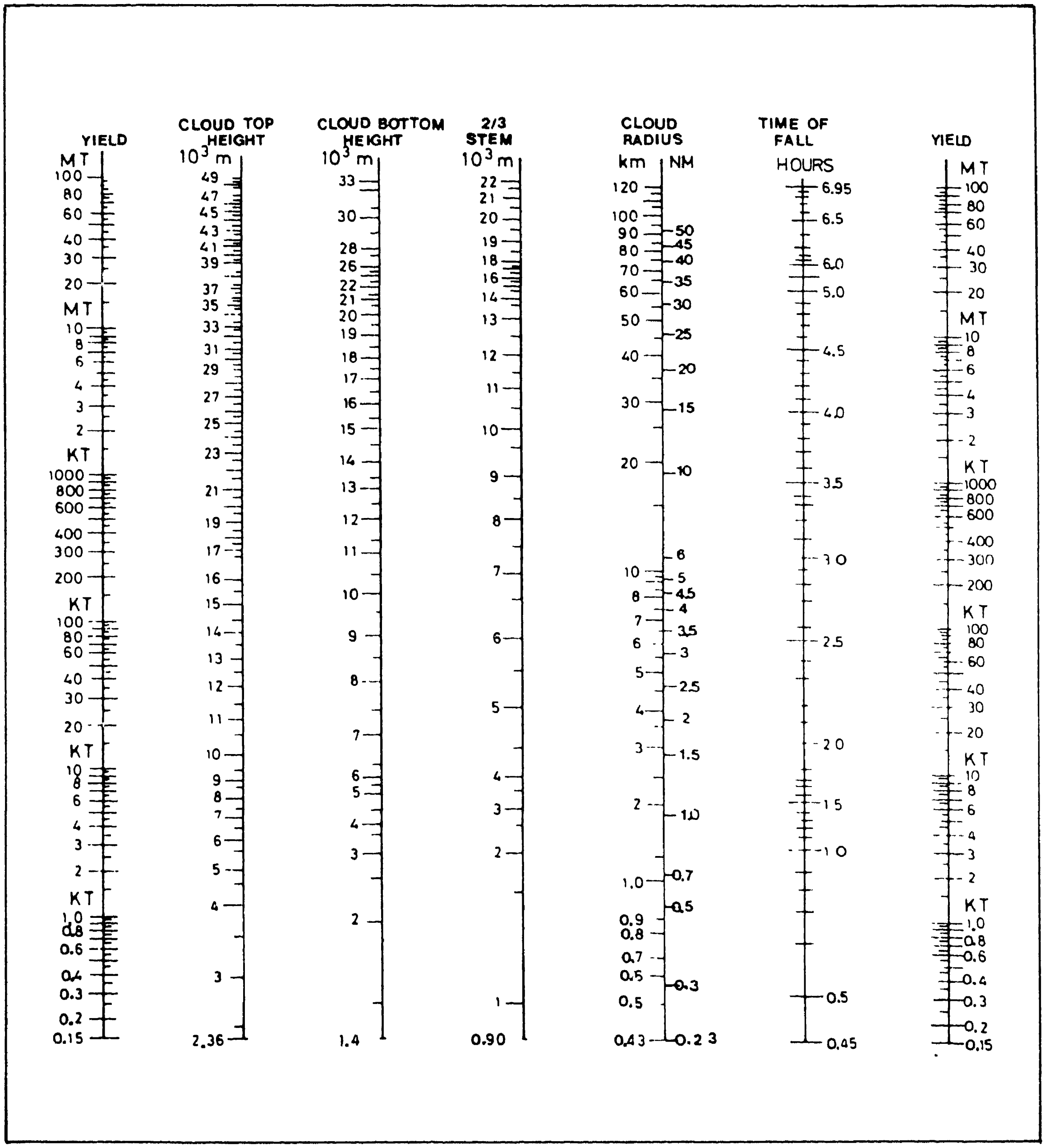


Figure 6-9-3.—Stabilized cloud and stem parameters.

The cloud top, bottom, and 2/3 stem heights are placed on the vector plot and labeled. Radial lines are then drawn between each of these points and GZ. See figure 6-9-4. The wind vectors between the 2/3 stem height and the cloud-top height are the vectors used in predicting the fallout area. If wind vectors between these two points extend outside the radial lines, you must expand the angle formed by the radial lines to include the outside vectors. An example of this is shown in figure 6-9-5.

EFFECTIVE DOWNWIND DIRECTION.— To determine the effective downwind direction (EDD), you must determine the sector angle formed between the radial lines GZ-CT and GZ-2/3 S and ground zero. If the angle is 40 degrees or greater, EDD is obtained by bisecting the angle. If the angle is less than 40 degrees, bisect the angle but then expand the angle to 40 degrees by drawing two additional radials. See figure 6-9-6. THE ORIENTATION OF THE BISECTING LINE IS THE EFFECTIVE DOWNWIND DIRECTION.

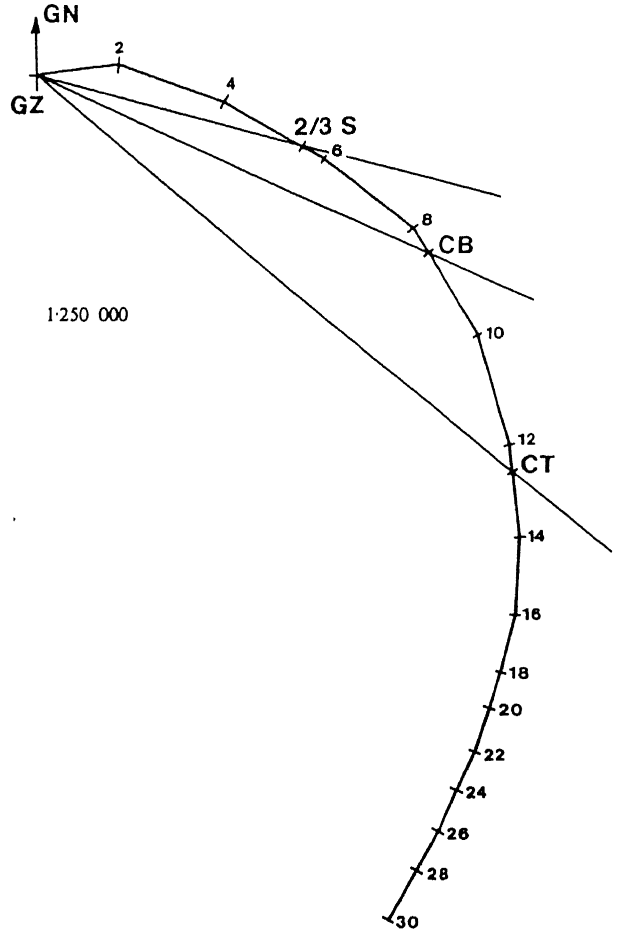


Figure 6-9-4.—Wind vector plot with cloud and stem radial lines.

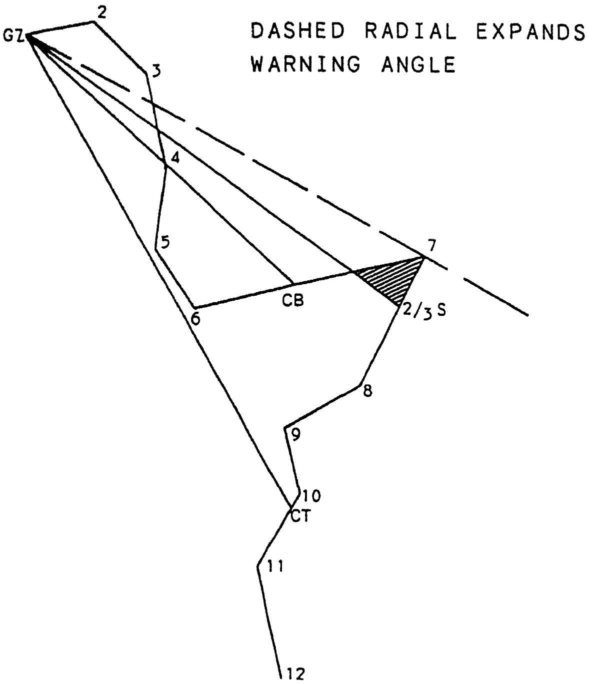


Figure 6-9-5.—Example of wind vectors extending beyond radials and angle expansion.

EFFECTIVE DOWNWIND FALLOUT SPEED.—The effective downwind fallout (EDF) speed is determined using the following steps:

1. Measure the length of the radial line from GZ to the cloud-bottom (CB) point.

2. Convert the length into kilometers, using the map scale on which the wind vector plot is drawn.

3. Compute EDF speed by using the following formula:

$$\text{EDF speed} = \frac{\text{distance from GZ to CB}}{\text{time to fall}}$$

Example: The distance between GZ and CB equals 26.0 centimeters. This distance equals 67 kilometers when using a map with a scale of 1:250,000 (1 kilometer = 4 millimeters). The time

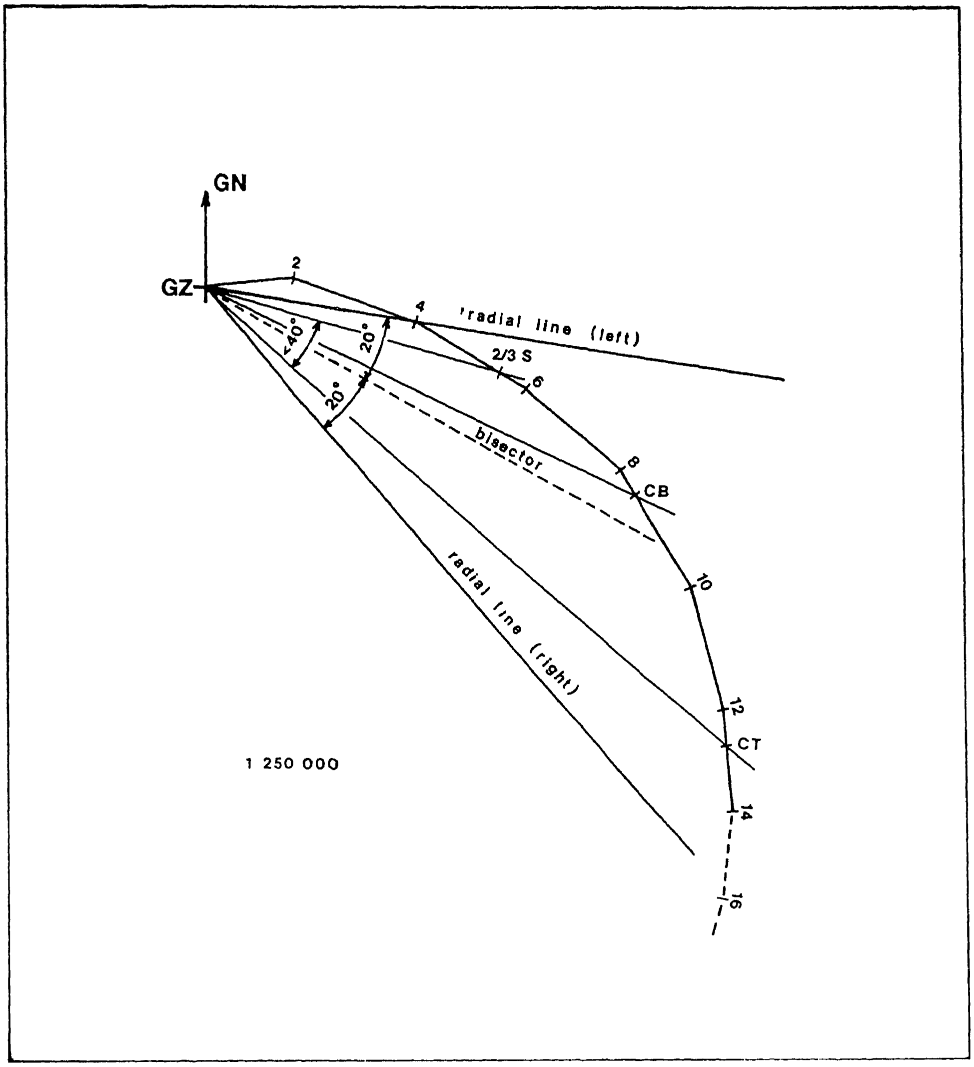


Figure 6-9-6.—Wind vector plot with expanded radial lines.

of fall from the cloud base associated with a 50-kt explosion is 2.35 hours. Then,

$$\text{EDF speed} = \frac{67 \text{ kilometers}}{2.35 \text{ hours}}$$

$$= 28.5 \text{ kilometers per hour.}$$

The effective down wind direction and effective fallout speed are used to determine the zones of hazardous fallout.

Fallout Zones

There are two hazardous fallout zones. Zone I is the Zone of Immediate Operational Concern, and Zone II is the Zone of Secondary Hazard.

ZONE I.—Exposed unprotected personnel in this zone may be subject to doses of radioactivity of 150 rads or greater in relatively short periods of time (less than 4 hours after actual arrival of RADFO). Major disruptions of unit operations and high casualty levels are possible.

ZONE II.—Within this zone, exposed unprotected personnel are expected to receive less than 150 rads within 4-hours of the RADFO's arrival. The emergency risk dose is 150 rads. Within the first 24 hours of the RADFO's arrival, dosages of 50 rads or greater may be expected. Personnel with no previous radiation exposure can continue critical missions for as long as 4 hours after the arrival of RADFO without incurring the 150-rad emergency risk dose.

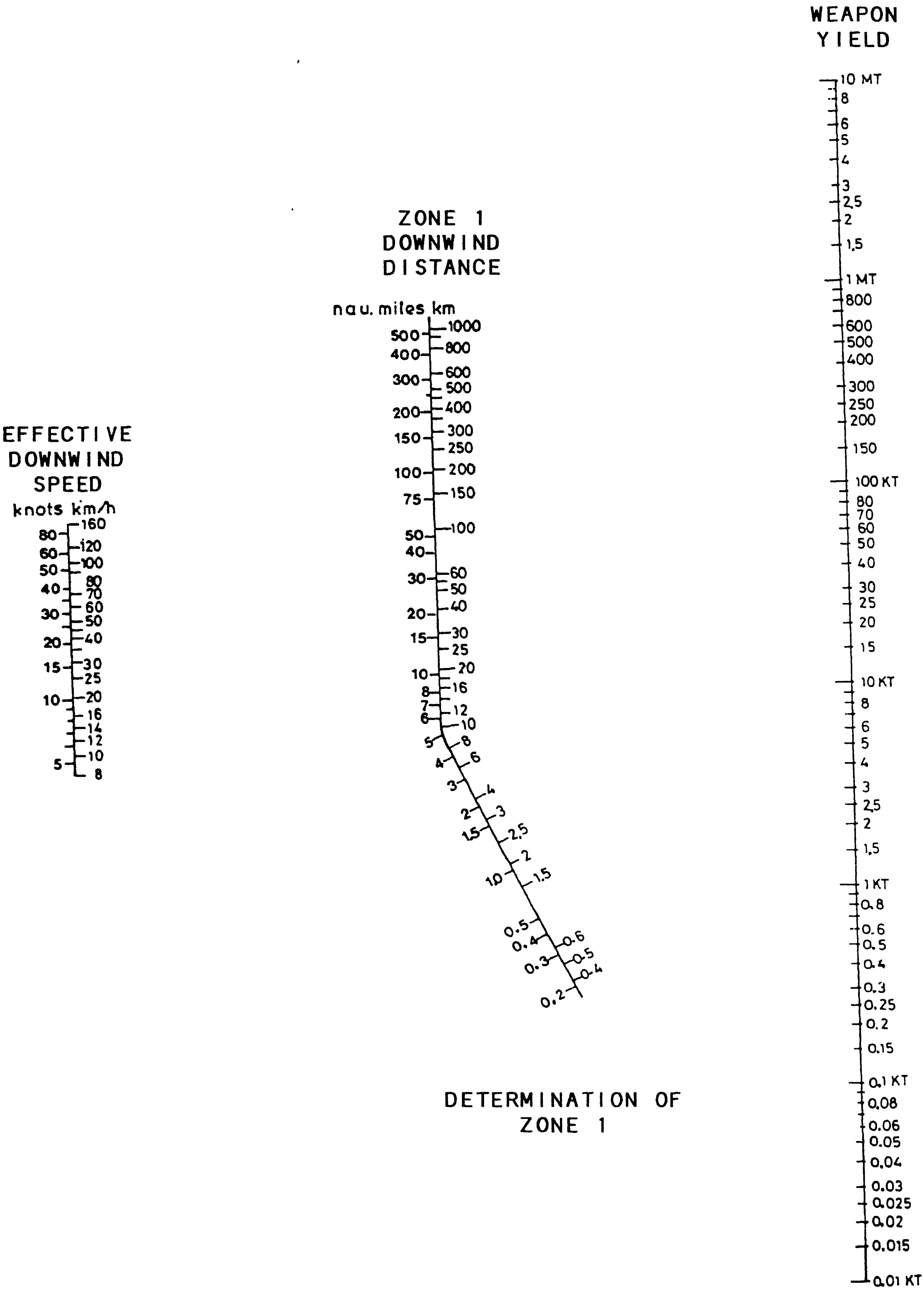


Figure 6-9-7.—Zone I downwind distance nomogram.

Outside these two zones, exposed unprotected personnel may receive a total dose of less than 50 rads in the first 24 hours after the arrival of RADFO.

Determine the downwind distance to Zone I using the nomogram in figure 6-9-7. Use a straightedge and draw a line from the weapon yield, on the scale on the right, to the EDF speed on the wind-speed scale. Read the downwind distance to the outer limit of Zone I where the straightedge intersects the center scale. To obtain the distance to the outer limit of Zone II, you simply multiply the distance to Zone I by 2. Draw arcs at these distances on the vector plot. See figure 6-9-8.

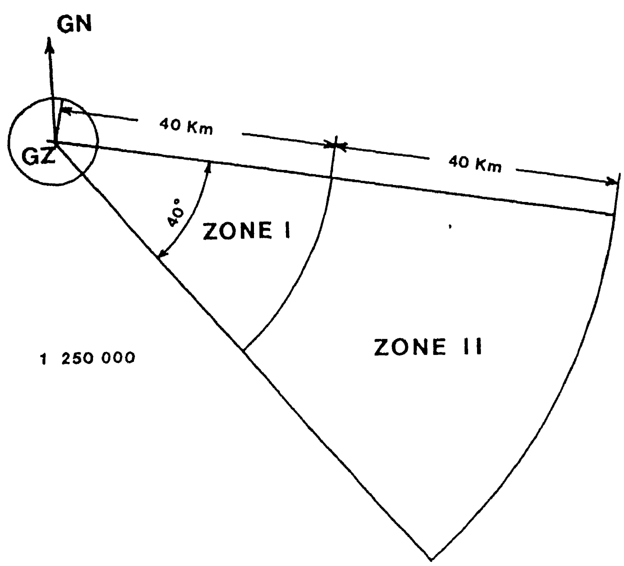


Figure 6-9-8.—Radial lines, cloud radius circle, and Zone I and Zone II arcs.

The boundaries of the fallout zones are determined as follows:

1. Determine the cloud radius, using the nomogram in figure 6-9-3.
2. Draw a circle around GZ, using the radius from step 1.
3. Draw two lines tangent to the cloud radius circle that intersect the downwind distance arc of Zone I and Zone II along the radial lines GZ-CT and GZ-2/3 S. See figure 6-9-9.

NOTE: In cases where the angle has been expanded, the expanded angle is used.

The estimated time that fallout will arrive at a particular location is a function of the EDF speed. For example, if the EDF speed is 20 kilometers per hour, the fallout is estimated to arrive at a point 20 kilometers downwind from GZ in 1 hour, 40 kilometers downwind in 2 hours, and so forth.

When the EDF speed is less than 8 kilometers per hour, the predicted fallout area will be circular. Two concentric circles are drawn around GZ that are equal to the Zone I and Zone II distances, respectively.

Figure 6-9-10 is an example of a completed detailed fallout plot. The final plot indicates the

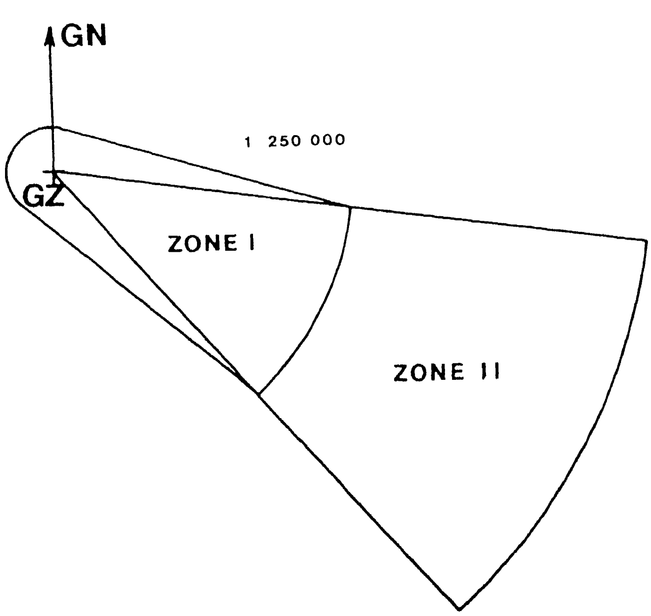


Figure 6-9-9.—Cloud radius circle and tangent lines.

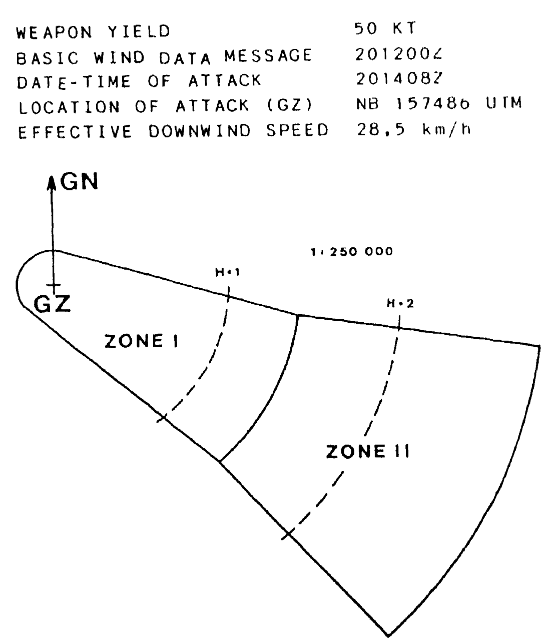


Figure 6-9-10.—Completed detailed fallout prediction.

map scale used, the weapon yield (estimated or actual), the date-time of the burst, the location of the burst, and the EDF speed.

Learning Objective: Diagram the zones of the most hazardous fallout using the information contained in the Effective Downwind Message.

EFFECTIVE DOWNWIND MESSAGE

An Effective Downwind Message (EDM) or Nav Effective Downwind Message contains the effective downwind fallout speed and direction for each of the seven weapon yields. You must use the downwind direction and speed that correspond to the weapon yield of a burst, should one occur, to determine the zones of the most hazardous fallout. The EDM transmitted to shore units is in the following format:

EFFECTIVE DOWNWIND MESSAGE	
ZULU	DDTTTTZ
ALPHA	dddfff
BRAVO	dddfff
CHARLIE	dddfff
DELTA	dddfff
ECHO	dddfff
FOXTROT	dddfff
GOLF	dddfff

The line *ZULU* contains the date (DD) and time (TTTT) (GMT or UTC) of the upper-wind observation used in determining the effective downwind directions and speeds for each yield. The effective downwind direction (ddd) is the direction toward which the wind is blowing, to the nearest whole degree. The EDF speed (fff) is in kilometers per hour. A direction and speed are given for each yield group except when the effective downwind speed is less than 8 kilometers per hour for a particular yield. When this occurs, the downwind distance to Zone I is transmitted instead of a dddfff group. The downwind distance is transmitted as a three-digit group only.

A three-digit group within parentheses may also appear in the EDM beside the effective downwind direction and speed: for example, FOXTROT 230030 (060). The group within parentheses represents the expansion angle to be used in constructing the RADFO diagram. Normally, the RADFO diagram is constructed using the information in the EDM and a 40-degree warning angle (20 on either side of the effective downwind direction). When the 40-degree warning angle is insufficient for a particular yield, the required expansion angle is transmitted within parentheses following the dddfff group. The expansion angle may also be transmitted as an additional digit added to the dddfff group (FOXTROT 2300306). When a seventh digit is used in any one yield group, all of the yield groups will contain seven digits. See figure 6-9-11.

EFFECTIVE DOWNWIND MESSAGE	
ZULU	271200Z
ALPHA	004----
BRAVO	007----
CHARLIE	210014/
DELTA	220016/
ECHO	225020/
FOXTROT	2300306
GOLF	2400356

Explanation of the 7th digit:

/ = 40° angle
5 = 50° angle
6 = 60° angle
7 = 70° angle
8 = 80° angle
9 = 90° angle
0 = 100° angle
1 = 110° angle
2 = 120° angle
3 = more than 120° angle
- = circle (EDW-speed less than 8 km/h).

Figure 6-9-11.—Example and explanation of EDM special case using seventh digit.

Fallout Prediction Overland

To predict the geographical areas that will be affected by the most hazardous fallout (aones 1 and 2), you will need the following:

- an EDM (effective downwind message) or your calculations of effective downwind direction (EDD) and effective downwind fallout (EDF) speed;
- a chart of the geographic region in the 1:50,000, 1:100,000, or 1:250,000 scale;
- a fallout template from the pocket on the end cover of the ATP-45 (there are three land templates [one for each of the above scales] and one unscaled shipboard-use template); and
- a report of a nuclear detonation giving the estimated yield, the location of the burst, the time of the burst, and height of the burst (assume a surface burst if the height of burst is not known or is not reported).

The fallout prediction procedure using an EDM for an overland detonation follows:

1. Determine which line of the EDM (ALPHA through GOLF) to use in the prediction procedure. For example, a 4-kiloton blast requires that you use the BRAVO line.
2. Draw a line on the (land) fallout template from GZ to the compass rose direction corresponding to the effective downwind direction determined in step 1. Place GN at the end of this line.
3. Determine the downwind distance to Zone I. Enter the nomogram (fig. 6-9-7) with the yield of the weapon and the downwind speed. REMEMBER: If the yield-group line you are using contains a three-digit group, the digits represent the downwind distance.
4. Double the distance obtained in step 3 to get the downwind distance to Zone II.
5. Scribe arcs between the two radial lines of the template at the Zone I and Zone II distances.
6. Draw lines from the specific yield group semicircle on the template (A or B or C) to the intersection points of the Zone I arc with the radial lines. See figure 6-9-12.
7. Draw the H+1 and H+2 time lines as dotted arcs. These lines represent the distances that the fallout will travel at the given downwind speed.
8. Label the template. Write in the map scale, estimated yield, location, date, and

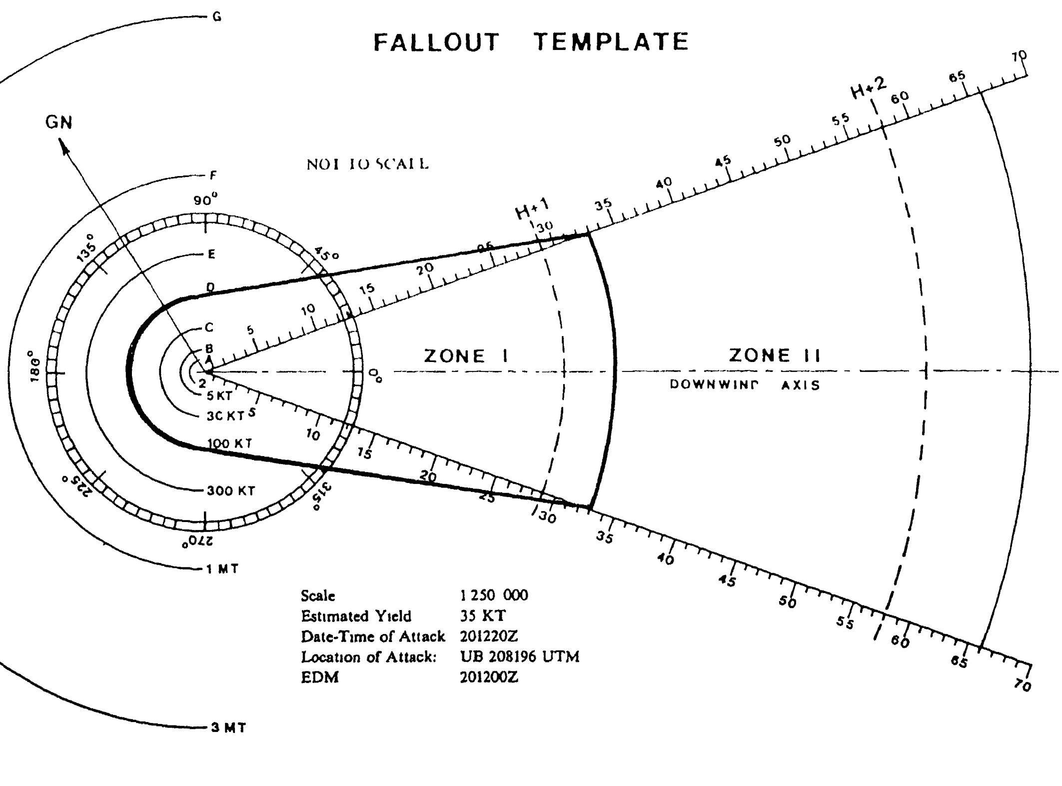


Figure 6-9-12.—Land fallout template showing intersection of Delta yield group lines with radials and Zone I arc.

time of the burst, and the EDM used in the prediction.

9. Overlay the template onto the chart. Place GZ over the station or location on the chart where the burst occurred and align the GN line with true north. The Zone I and II areas are now visible on your chart.

Example:

One hour ago, at 2120Z, a surface nuclear detonation occurred at Bonn, West Germany. The estimated yield of the burst was 35 kilotons. You are working with a map that has a scale of 1:250,000, and the daily EDM has been received:

EFFECTIVE DOWNWIND MESSAGE

ZULU	201200Z
ALPHA	095020
BRAVO	102024
CHARLIE	115028
DELTA	122029
ECHO	126029
FOXTROT	132029
GOLF	140035

Based on the information above, prepare a fallout prediction as follows:

1. Use the Delta line of the EDM, because the weapon yield (35 kt) is between 30 and 100 kilotons.

2. Draw the GN line on the template. It should extend from the center of the yield semicircles through 122 degrees on the compass rose. See figure 6-9-12.

3. Determine the downwind distance of Zone I using the nomogram (fig. 6-9-7), the effective downwind speed (029 km/h), and the yield (35 kt). Your answer should be 33 kilometers.

4. Double the Zone I distance (33 kilometers) to get the distance to Zone II (33 kilometers × 2 = 66 kilometers.

5. Scribe arcs between the two radial lines on the template at 33 and 66 kilometers.

6. Draw lines from the Delta yield group semicircle on the template to the intersection points of the 33-kilometer arc with the radials. See figure 6-9-12.

7. Draw the H+1 and H+2 time lines as dotted arcs at 29 and 58 kilometers.

Scale:	1:250,000
Estimated Yield:	35 kt
Date-Time of Attack:	202120Z
Location of Burst:	Bonn, West Germany
EDM:	20/1200Z Sept. 89

9. Overlay the template on a 1:250,000 Europe chart. Place GZ of the template over the location of Bonn, West Germany and align the GN line with true north. The areas of most hazardous fallout can now be seen on the chart.

Fallout Prediction at Sea

Fallout predictions for naval ships are based upon the same principles as those previously discussed for fallout prediction overland. However, there are some differences.

GEOGRAPHICAL CHARTS.—The geographic charts used by ships are not uniformly scaled; and even on a specific chart, the scale can vary with latitude.

TEMPLATE.—The shipboard RADFO TEMPLATE is shown in figure 6-9-13. Although similar to the land template, there are differences. The main difference is that the semicircles upwind of GZ on the shipboard template do not reference preselected yield cloud radii. Also, the radial lines 20 degrees to the left and right of the downwind axis are without units of measurement. There is also a table on the shipboard template from which cloud radius and safety distances are indicated for each of the seven standard yield groups of the EDM.

NAV EDM.—In the NAV EDM, the DDTTTTZ group is the date and the time at which the actual wind conditions were measured or the time for which the winds are forecast. Normally, the message is valid for 6-hours from the time the winds were measured. The effective downwind direction is entered to the nearest whole degree, and the speed is in knots. When the effective downwind speed is less than 5 knots for a given yield group, the dddfff group is not transmitted. Instead, the downwind distance is transmitted as a three-digit group only.

Diagraming Fallout Zones

The diagraming procedure used at sea is the same as that used by land forces with the exception of using the shipboard template.

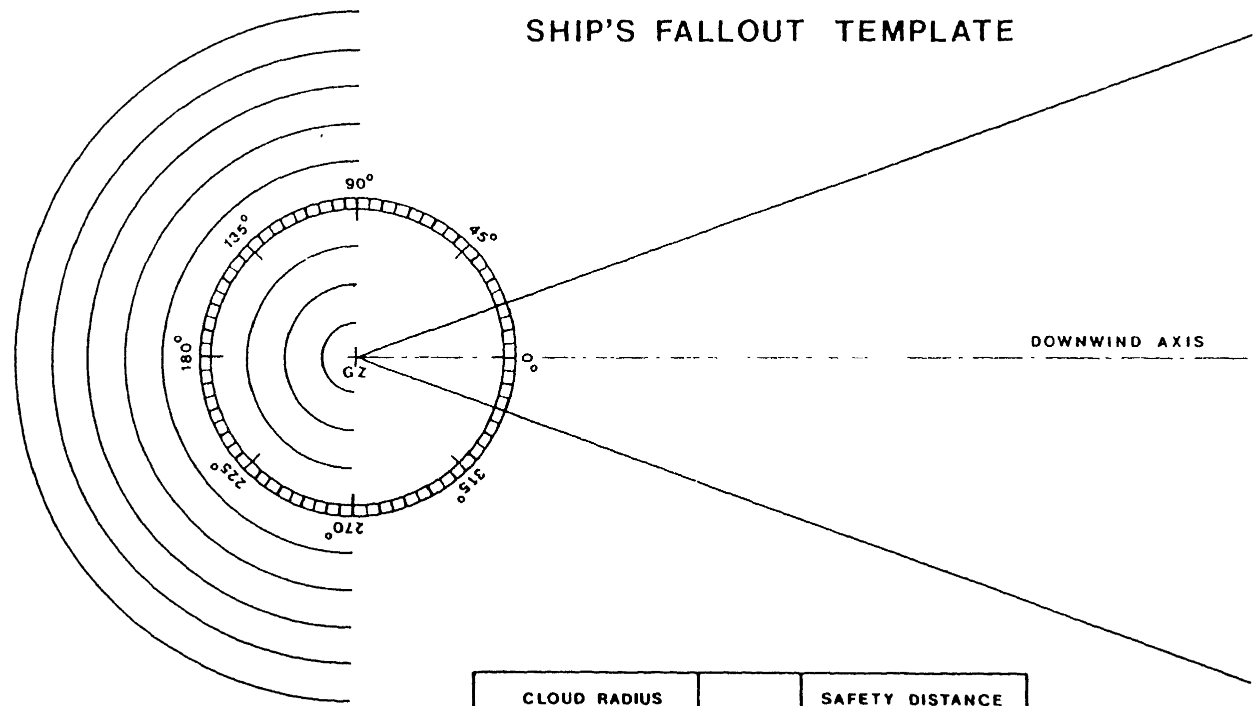
Determining Time of Fallout Arrival

Fallout does not occur simultaneously within the predicted fallout zones. It begins to fall in the vicinity of GZ and moves through the zones at the approximate speed of the effective fallout wind.

After plotting the zone of most hazardous fallout, determine the arrival time of the fallout at the sea surface, using the following procedure:

1. Multiply the effective downwind speed by the time (in hours) elapsed since the detonation to determine the distance the fallout has traveled.

2. Add and subtract a safety distance. Safety distance is provided on the ship's fallout template for the standard yield groups, or it can be



	CLOUD RADIUS								SAFETY DISTANCE						
YIELD	A	B	C	D	E	F	G		A	B	C	D	E	F	G
NAUTICAL MILES	0.7	1.0	2.3	3.7	6.1	9.7	15		1 3	1 5	3.4	5	7	13	19
KILOMETERS	1.2	1.9	4.2	6.8	11.2	18	28		2.5	3.0	6.7	10	14	25	36

Figure 6-9-13.—Ship's Fallout Template.

determined from the graph in figure 6-9-14. Safety distance allows for unlimited cloud size, diffusion, and wind fluctuations.

3. Plot the distance obtained in step 1, and the two safety distances obtained in step 2 on the template using GZ as the center. Draw these distances as two arcs across the fallout pattern between the radial lines. In most cases, the area enclosed by the two safety distance arcs and radial lines is the zone of deposited fallout (at the surface) at the specified time after detonation.

Example:

Determine the area where the fallout will fall 1.5 hours after detonation with an effective downwind speed of 16 knots. Determine safety distances, using yield group Delta.

16 knots × 1.5 hours = 24 nautical miles (nmi)

With GZ as the center and 24 nmi as the radius, draw a dotted arc across the fallout field at 24 nmi. This arc represents the middle of the area within which fallout may be expected to reach the surface at H+1.5 hours. From the template, the safety distance for yield group Delta is 5 nmi. Add 5 nmi to and subtract 5 nmi from 24 nmi:

$$24 + 5 = 29 \text{ nmi}$$

$$24 - 5 = 19 \text{ nmi}$$

Draw two arcs across the fallout pattern at these two distances. The area delineated by the two arcs and the radial lines (cross-wind boundaries) of the fallout area defines the approximate area of fallout deposition at 1.5 hours after the detonation. See figure 6-9-15.

Learning Objective: Compute effective downwind directions and speeds using standard-pressure-level winds.

COMPUTING EFFECTIVE FALLOUT WINDS USING STANDARD-PRESSURE-LEVEL WINDS

When RADFO messages are not available (that is, when there is no Basic Wind Data

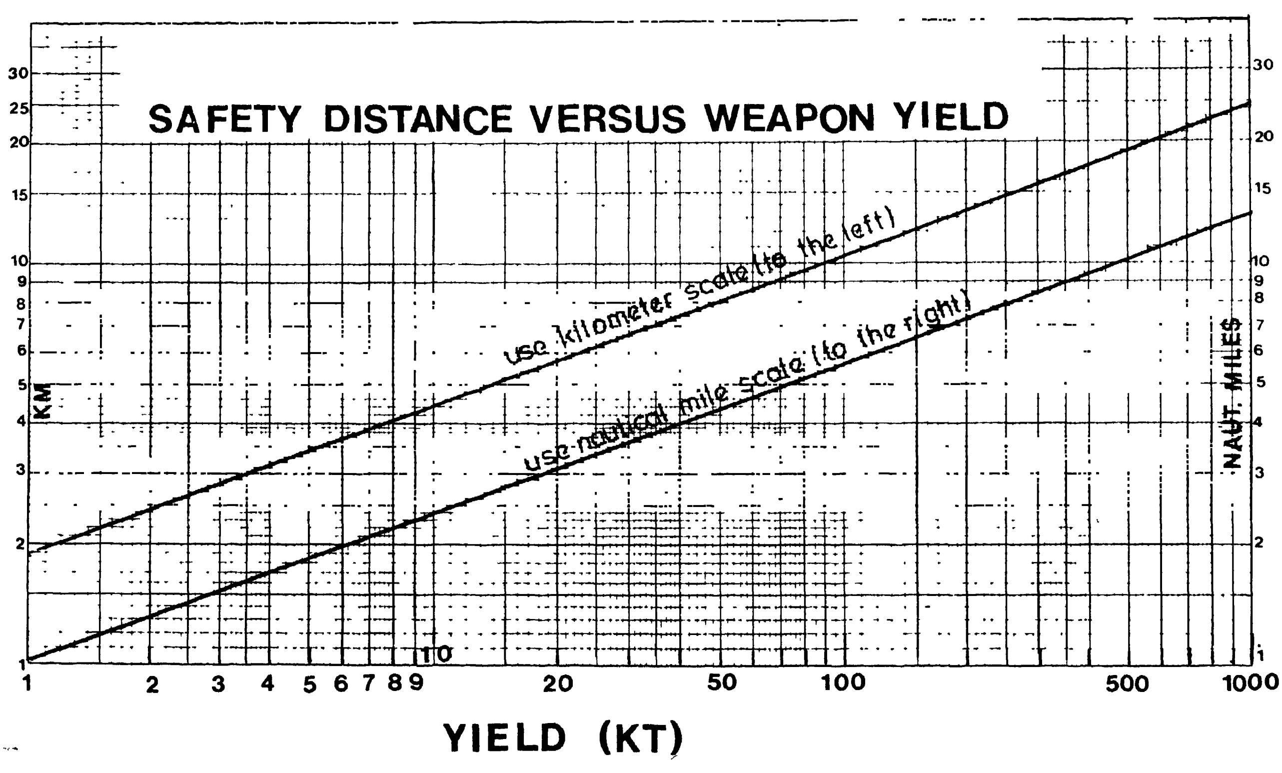
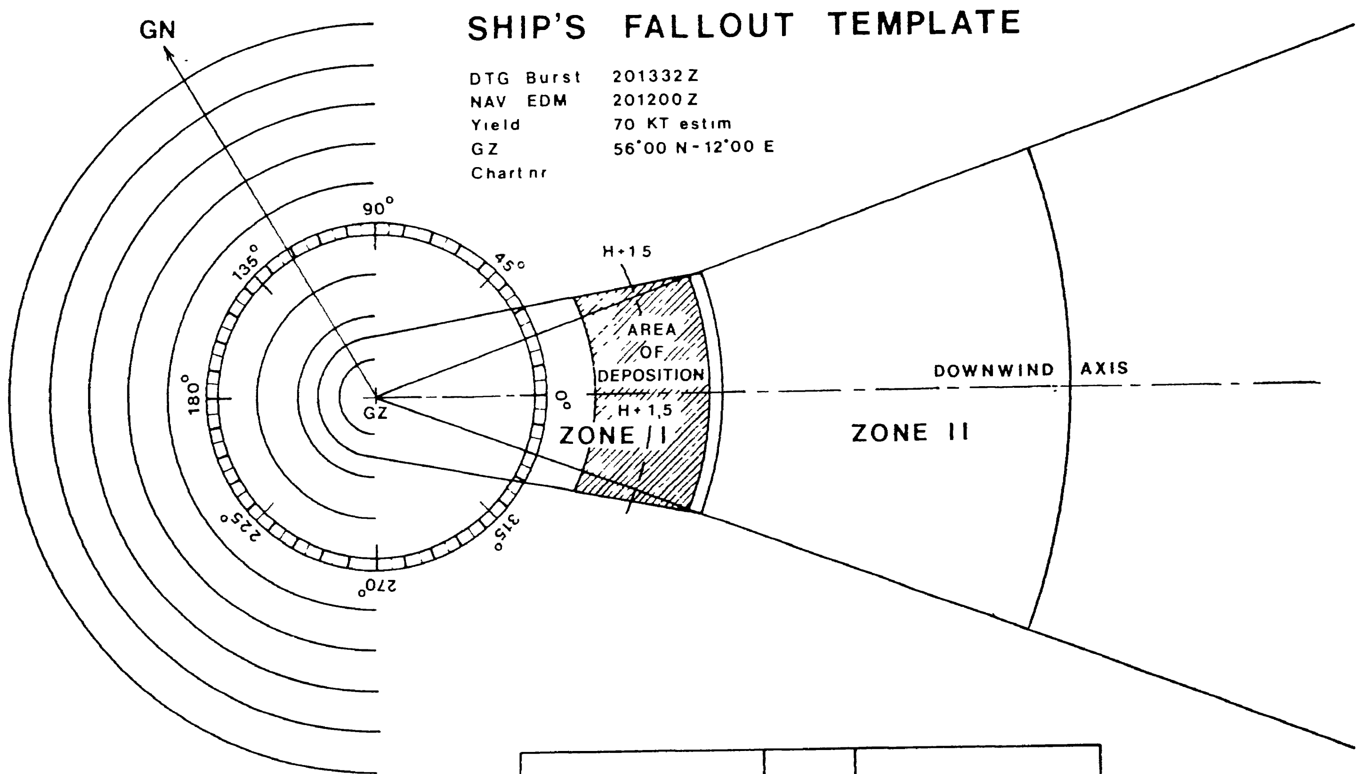


Figure 6-9-14.—Safety distance as a function of weapon yield.



	CLOUD RADIUS								SAFETY DISTANCE						
YIELD	A	B	C	D	E	F	G		A	B	C	D	E	F	G
NAUTICAL MILES	0 7	1 0	2 3	3 7	6 1	9 7	15		1.3	1.5	3.4	5	7	13	19
KILOMETERS	1 2	1 9	4 2	6 8	11 2	18	28		2 5	3 0	6 7	10	14	25	36

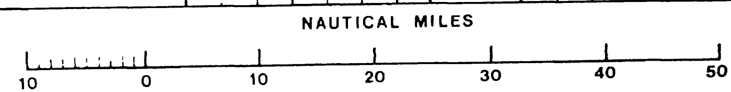


Figure 6-9-15.—Fallout diagram showing area of fallout at H+1.5 and safety distances.

Message or Effective Downwind Message with which to work), fallout predictions are still possible. Effective downwind direction and speed can be computed using a pre-determined or an estimated weapon yield and wind data obtained from upper-air soundings.

The use of standard-pressure-level winds to compute effective downwind data assumes that these winds represent mean winds for the layers of the atmosphere. Each standard pressure level applies to a certain layer of the atmosphere. See table 6-9-4. For example, the wind at 700 millibars is assumed to be the mean wind in the layer between 7,400 feet and 14,100 feet, and the wind at 500 millibars is assumed to be the mean wind for the layer from 14,100 feet to 21,000 feet. Table 6-9-4 also provides the nuclear-cloud-bottom parameters for the seven standard weapon yields (Alpha through Golf).

The standard-pressure-level winds used to compute the effective downwind direction and speed for a given weapon yield are those winds representing the layers up to and including the height of the nuclear cloud base. In other words, if the nuclear cloud base is estimated to be at 30,000 feet, only those layers up to and including this height are used.

Table 6-9-4.—Atmospheric Layers and Standard Pressure Levels; Cloud Base (Bottom) Parameters for the Seven Yield Groups

STANDARD PRESSURE LEVEL				WEAPON	
PRESSURE mb	HEIGHT (Thousands of Feet)	LAYER RANGE (Thousands of Feet)	NUCLEAR CLOUD BASE (Thousands of Feet)	YIELD	GROUP
1000	0.3	0 - 2.5			
850	4.8	2.5 - 7.4			
700	9.9	7.4 - 14.1	8.5	2 kt	A
			14.1	5 kt	B
500	18.3	14.1 - 21.0			
400	23.6	21.0 - 26.8	24.9	30 kt	C
300	30.1	26.8 - 32.1	30.5	100 kt	D
250	34.0	32.1 - 36.4	36.1	300 kt	E
200	38.8	36.4 - 41.8			
150	44.7	41.8 - 48.9	44.3	1 MT	F
100	53.2	48.9 - 56.9	51.8	3 MT	G

NOTE: The first standard pressure level is the 1,000-millibar level; however, if the 1000-millibar wind is not available, the surface wind should be used.

The standard-pressure-level winds must be weighted and vectorially added. The weighting is required to account for atmospheric layer thickness and the various densities of the layers. Weight factor tables are available for wind speeds in knots and in kilometers per hour. See tables 6-9-5 and 6-9-6. The weight factors are applied to the wind speed for each level. To obtain the weighted wind speed, you simply multiply the wind speed for each standard pressure level by the appropriate weight factor.

Vector Plots

To vectorially add the weighted wind speeds and directions, you must construct a wind vector plot as follows:

1. Label GZ and the GN line.

Table 6-9-5.—Weight Factors to Obtain EDF Speed in Knots

YIELD GROUP	NUCLEAR CLOUD BOTTOM (Thousands of Feet)	STANDARD PRESSURE LEVELS (mb)									
		1000	850	700	500	400	300	250	200	150	100
A	8.5	0.33	0.56	0.11							
B	14.1	0.21	0.36	0.43							
C	24.9	0.14	0.24	0.29	0.22	0.11					
D	30.5	0.12	0.22	0.26	0.20	0.13	0.07				
E	36.1	0.11	0.20	0.23	0.18	0.13	0.09	0.06			
F	44.3	0.10	0.18	0.21	0.17	0.11	0.09	0.06	0.06	0.02	
G	51.8	0.10	0.17	0.20	0.16	0.10	0.08	0.06	0.06	0.05	0.02

Table 6-9-6.—Weight Factors to Obtain EDF Speed in Kilometers-per-hour

YIELD GROUP	NUCLEAR CLOUD BASE km	STANDARD PRESSURE LEVELS (mb)									
		1000	850	700	500	400	300	250	200	150	100
A	2.6	0.61	1.04	0.20							
B	4.3	0.39	0.67	0.79							
C	7.6	0.26	0.45	0.53	0.41	0.20					
D	9.3	0.23	0.40	0.47	0.37	0.25	0.13				
E	11.0	0.21	0.36	0.43	0.33	0.24	0.17	0.11			
F	13.5	0.19	0.33	0.39	0.31	0.21	0.16	0.11	0.11	0.04	
G	15.8	0.18	0.32	0.37	0.29	0.20	0.15	0.11	0.10	0.10	0.03

2. From GZ, plot (draw) the first vector toward the downwind direction. Vector length can be made to a scale of your choice. For example, if you want 1 knot to equal 2 centimeters, a 10-knot wind will result in a vector length of 20 centimeters.

3. Draw the second vector from the end of the first vector. You proceed in this manner up to the yield level with which you are working.

4. After drawing the last vector, draw a straight line from GZ to the end of the last vector. This is the effective downwind direction.

5. To obtain the effective downwind speed, measure the straight-line distance between GZ and the end of the last vector and convert the distance in centimeters into knots.

Procedure

The procedure used in computing the effective downwind speed and direction for a particular yield is as follows:

1. Obtain the winds for the standard pressure levels.
2. Convert the winds into vectors by adding or subtracting 180 degrees.
3. Select the weight factors to be applied to the reported wind speeds for each level affected by the selected yield groups.
4. Calculate the wind vector lengths by multiplying the wind speed for each standard pressure level by the appropriate weight factor.
5. Construct the wind vector plot using the weighted wind speeds and directions.
6. Determine the effective downwind speed and direction.

Examples of upper-air-sounding information are as follows:

Surface	250°	08 knots
850 mb	300°	10 knots
700 mb	300°	10 knots
500 mb	320°	15 knots
400 mb	290°	10 knots
300 mb	270°	15 knots
200 mb	280°	15 knots
150 mb	290°	20 knots
100 mb	320°	25 knots

Problem: Compute the effective downwind direction and speed for a weapon yield in group DELTA (31 - 100 kt).

1. Compute wind vector direction for each level from the surface up to 300 millibars by adding or subtracting 180. The 300-millibar level is the last level used because it is the level that corresponds to the delta yield group.

Surface = 070°

850 mb = 120°

700 mb = 120°

500 mb = 140°

400 mb = 110°

300 mb = 090°

2. Calculate the wind vector lengths by multiplying the wind speed for each standard pressure level by the appropriate weight factor.

1000 mb (Surface)	08 knots × 0.12 = 0.96 knots
850 mb	10 knots × 0.22 = 2.2 knots
700 mb	10 knots × 0.26 = 2.6 knots
500 mb	15 knots × 0.20 = 3.0 knots
400 mb	10 knots × 0.13 = 1.3 knots
300 mb	15 knots × 0.07 = 1.05 knots

3. Construct the wind vector plot. See figure 6-9-16. In that example, the map scale 1 knot = 2 centimeters was used.

4. For the Delta weapon yield group, the effective downwind direction is 117° and the effective downwind speed is 10.6 knots.

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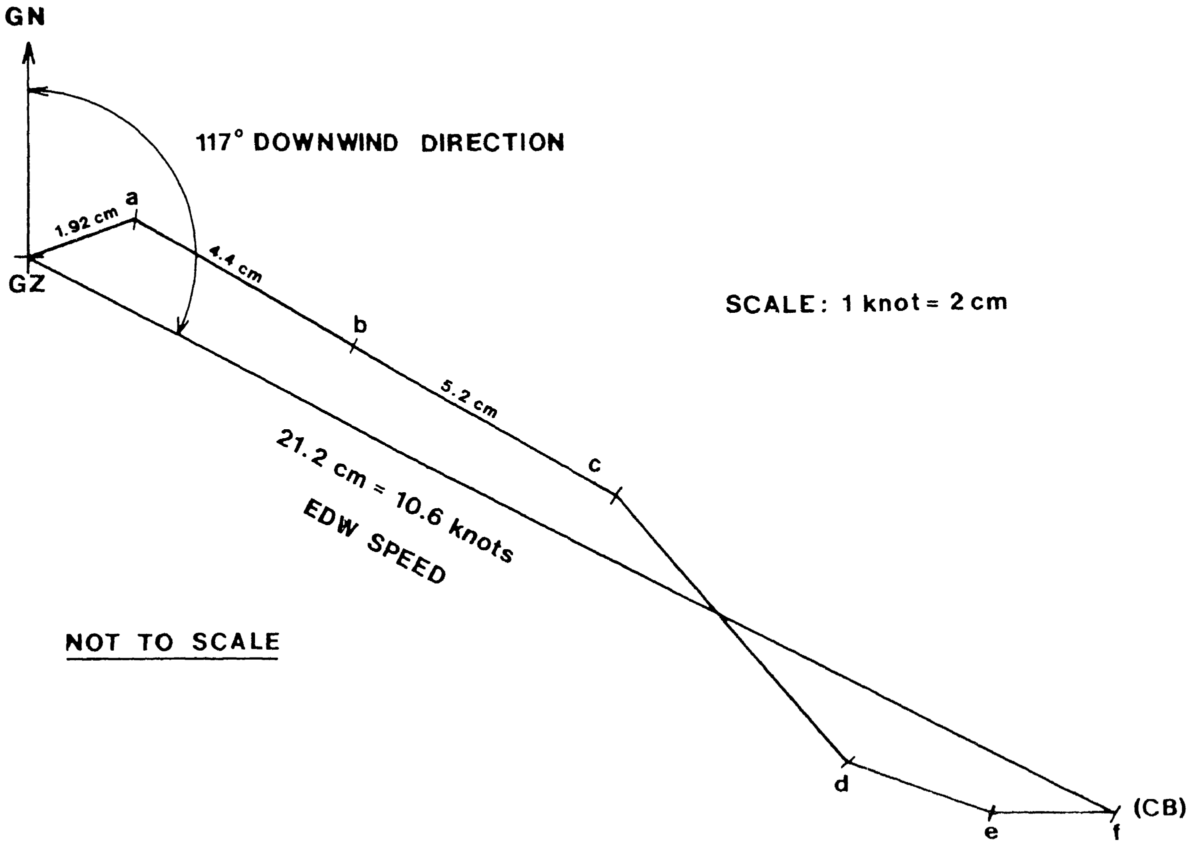

Figure 6-9-16.—Delta yield group wind vector plot.

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UNIT 7

ADMINISTRATION

FOREWORD

The purpose of this unit is to help you accomplish the routine administrative tasks you will be asked to perform as an Aerographer's Mate Second Class Petty Officer. The vast majority of the AG2 billet descriptions refer to Analyst/Forecaster Assistants. Most of the larger Naval Oceanography Command units have an AG2 assigned as the Records Petty Officer. Both jobs require administrative knowledge.

As an Analyst/Forecaster Assistant, ashore or at sea, you will be required to act as the intermediate link in the chain of command between the forecaster and the personnel in the duty section, a job normally listed on the watch bill as the Section Leader. You will find it necessary to make more decisions than you did as a Third Class Petty Officer; the Airmen and Third Class Petty Officers will come to you for information and advice about your command, other units in the Naval Oceanography Command, and general information about the Aerographer's Mate rating and the Navy. You will find that a thorough knowledge of the structure of the Naval Oceanography Command will be needed for you to answer many of those questions. You will be required during the next few years to find information in instructions, other publications, and filing systems. You may likely be assigned to review and update filing systems, instructions, and publications. You no doubt will be tasked to properly dispose of old files, meteorological/oceanographic records, and charts.

In this unit, we cover the basics of the knowledge you will need to have about administration that is unique to the Aerographer's Mate Rating. While this material is generally covered by general military occupational standards, it is not addressed until the E-7 level, in *Military Requirements for Chief Petty Officer*.

To function effectively as an AG2, you will also need additional information about administration (supply duties, collateral shipboard duties, shipboard watch-standing duties, naval programs, advancement, etc.), which is not unique to the AG rating. This information is covered in *Military Requirements for Petty Officer Second Class*.

UNIT 7—LESSON 1

MAINTENANCE OF METEOROLOGICAL AND OCEANOGRAPHIC FILES, RECORDS, DIRECTIVES, PUBLICATIONS, AND CHARTS

OVERVIEW	OUTLINE
Define terms associated with the maintenance of meteorological and oceanographic files, records, directives, publications, and charts.	General information Organization of files and directives Maintenance of files and records
Identify the terms, manuals, and tasks associated with the maintenance of meteorological and oceanographic files, records, directives, publications, and charts.	Maintenance of directives Maintenance of meteorological and oceanographic publications Maintenance of plotting charts

MAINTENANCE OF METEOROLOGICAL AND OCEANOGRAPHIC FILES, RECORDS, DIRECTIVES, PUBLICATIONS, AND CHARTS

As an Aerographer's Mate Second Class, you should be able to locate various information in publications, directives, and files. You may be tasked to maintain a set of files or to update publications or directives. In this lesson, we cover the basic information you will need to locate information and to maintain files, publications, and directives.

Learning Objective: Define the terms *directive*, *instruction*, *notice*, *change transmittal*, *files*, *records*, *publications*, *charts*, **and** *forms*.

GENERAL INFORMATION

Before we discuss techniques on locating information and maintaining these informational resources, we must define the terms that we will use. The resources we are most interested in and their definitions are as follows:

- *Directive*—A written statement that officially prescribes or establishes policy, methods, or procedures. It may require action or simply provide information for an activity's administration or operation. Directives have the effect of orders issued by the signing authority. Directives are issued as *instructions*, *notices*, and *change transmittals*.

- *Instruction*—A directive containing authority or having a continuing reference value, or requiring continuing action. It remains in effect until superseded or cancelled by the originator or higher authority. In the Marine Corps, instructions are referred to as *orders*.

- *Notice*—A directive of a one-time or brief nature and contains a self-cancelling provision. Notices have the same force as instructions. Notices usually remain in effect less than 6 months, and, by definition, should not be effective for longer than 1 year. Notices are called *bulletins* in the Marine Corps.

- *Change Transmittal*—A written set of directions used to correct, update, or modify an existing instruction. Although not normally done,

change transmittals may also be used to correct notices.

- *Files*—Collections of information, usually organized by subject, that may include information or material about the subject. Information may be original written material or reproduced copies, and may be in the form of notes, rough drafts, final typed, or published information. Files may also contain material such as art, drawings, photographs, magnetic media (tapes, floppy disk, hard disk, etc), light media (films, transparencies, laser disks, etc), samples, models, prototypes or evidence. Files may contain *records*.

- *Records*—As officially defined (82 Statute 1299 as amended [44 United States Code 3302-3314, Chapter 33]), include "all books, papers, maps, photographs, machine-readable materials, or other documentary materials, regardless of physical form or characteristics, made or received by an agency of the United States Government under Federal law or in connection with the transaction of public business, and preserved, or appropriate for preservation, by that agency or its legitimate successor, as evidence of the organization, functions, policies, decisions, procedures, operations, or other activities of the Government, or because of the informational value of the data in them. Library and museum material made or acquired or preserved solely for reference or exhibition purposes, extra copies of documents preserved only for convenience of reference, and stocks of publications and of processed documents, are not included."

- *Publication*—Any pamphlet, book, or collection of information, other than a directive, reproduced by mechanical methods by the government or a private agency for distribution within the government or to the public.

- *Charts*—Any maps, drawings, or diagrams depicting information. In this lesson, we will be referring to weather plotting charts (printed maps used to plot weather data), facsimile charts (facsimile reproductions of plotted and analyzed weather products), and recorder charts (machine plotted traces of record information).

- *Forms*—Preprinted paper documents that use blank lines or spaces for the entry of information.

Learning Objectives: Identify the manual that contains instructions on how to organize meteorological and oceanographic files and directives. Identify the major categories of the Standard Subject Identification Code System. Identify the directives that list effective instructions from the various Naval commands.

ORGANIZATION OF FILES AND DIRECTIVES

In the Navy, both files and directives are organized according to the Standard Subject Identification Code System, using Standard Subject Identification Codes (SSICs). The reference manual used to assign codes for specific subjects is SECNAVINST 5210.11, *Department of the Navy File Maintenance Procedures and Standard Subject Identification Codes (SSIC)*, often referred to as the SSIC Manual. Instructions are provided to help you assign a code for any subject you are concerned with. The instruction specifically states that all Navy and Marine Corps letters, messages, directives, forms, and reports should be assigned an SSIC (by the originator).

The SSICs are used as the basis for filing all information received or originated as letters, messages, directives, forms, or reports.

There are thirteen *major subject groups* in the SSIC system, each designated by the thousands digit(s) in a four- or five-number code, as follows:

CODES	MAJOR SUBJECT GROUP
1000 to 1999	Military Personnel
2000 to 2999	Telecommunications
3000 to 3999	Operations and Readiness
4000 to 4999	Logistics
5000 to 5999	General Administration and Management
6000 to 6999	Medicine and Dentistry
7000 to 7999	Financial Management
8000 to 8999	Ordnance Material
9000 to 9999	Ships Design and Material
10000 to 10999	General Material
11000 to 11999	Facilities and Activities Ashore
12000 to 12999	Civilian Personnel
13000 to 13999	Aeronautical and Astronautical Material

Each major subject category is broken down into *primary subjects*, as identified by the hundreds digit of the code. The primary subjects are broken down into *secondary subjects*, as identified by the tens digit in the code. The last digit in the code, the ones digit, reflects a tertiary subject. The SSIC Manual assigns codes through the secondary subjects in all cases, and through the tertiary subjects in many cases. Codes may be assigned locally, using numbers following a decimal point, to further break down or classify a subject. As an example, the code used for NAVOCEANCOMINST 3142.1 represents the major subject group 3000, for *Operations and Readiness*; the primary subject 100, *Operations*; the secondary subject 40, for *Geophysical and Hydrographic or Mapping, Charting, and Geodesy Support, General*; and the tertiary subject 2, for *data collection*. NAVOCEANCOM assigned the decimal code **.1** to identify Pilot Weather Reports (PIREPS).

As an AG2, you will rarely be required to assign an SSIC to a subject. All incoming Naval message traffic and most Naval correspondence will contain an SSIC. In message traffic, the SSIC is the five-digit number in solidi following the message classification. You have certainly seen observations before that have contained the classification line **U N C L A S //N03142//**. The *N* means a Navy SSIC follows, and the *3142* is the SSIC. In naval messages, the code is always expressed as a five-digit number, and only codes down to the tertiary subject-level are used.

All Naval letters and some memoranda will contain SSICs. Naval letters will contain a four- or five-digit SSIC as the first entry in the *Reply/Refer to*: block on the right side of the page following the letterhead. Of the four Naval memorandum formats, the two formats that may be used for inter-command memoranda are the *letterhead memorandum*, printed on the command's letterhead paper, and the *memorandum-for*, also printed on the command's letterhead. Both of these formal memoranda formats must contain an SSIC in the same manner as the Naval letter. You may use these assigned SSICs as the basis for filing the material, if filing is required.

The two informal memoranda formats used only for intra-command (inter-office) memos, normally do not contain SSICs. Often, the informal memoranda contain information of little continuing value, and rarely require filing. Usually, informal memoranda (in the Navy geophysics community) are hung on clipboards until the event listed in the memo passes, then the memo is trashed or burned.

The SSIC manual should be used as the basic guide for assigning codes to subjects, when SSICs have not previously been assigned. For convenience of use, the SSIC Manual is broken down into a numerical, code-to-subject, section as well as an alphabetical, subject-to-code, section. However, the manual often does not assign codes in sufficient detail to cover every subject. Using the group, primary subject, secondary subject, and (if provided) tertiary subject codes the manual yields as guide, refer to the index of Naval Oceanography Command instructions or your command's instruction index to locate instructions with the same SSIC code (through the tertiary code) for the subject you are attempting to classify. You will often find a notice or an instruction dealing with the subject, and these directives will have a subject specific SSIC. It is not uncommon to find many subdivisions of a tertiary code using decimal codes from .11 to .99.

At least once a year, Naval Oceanography Command issues a notice, NAVOCEANCOM-NOTE 5215, that lists all the current Naval Oceanography Command instructions. This notice may be used as an index for the instructions. Another directive, NAVPUBINST 5215.1, updated annually, lists not only effective Naval Oceanography Command instructions, but instructions for all of the major Naval commands, called *Washington-headquartered commands*. It contains five sections of listings: (1) a consolidated subject index; (2) an alphabetical listing of instruction subjects, by command; (3) a numerical listing of instructions, by command; (4) a cancellation listing, by command; and (5) a DOD implementation listing. Of these, the consolidated subject listing is an excellent source to research subjects and SSICs. The alphabetical and numerical listings both provide listings of Naval Oceanography Command instructions.

Learning Objectives: Define the terms *cutoff date*, *retention period*, *transfer date*, **and** *disposal date*. **Identify the tasks involved with maintenance of files.**

MAINTAINING FILES AND RECORDS

When you are given the job of maintaining a set of files, more is involved in the job than just

stuffing incoming paperwork into drawers of a filing cabinet. In this section, we define some of the terms used to discuss information and filing system procedures, outline the tasks involved in maintaining a filing system, and list the retention periods of the common types of meteorological and oceanographic information.

Terms Used to Describe Information and Filing Procedures

Files are designed to hold information accessible for reference. The length of time that material is held is determined by the type of information. The Secretary of the Navy has defined two basic types of informational material, based upon the importance of the information for future applications:

- *Permanent records*—Informational material and records necessary to protect the Navy's interests and to insure proper documentation of the Navy's significant experiences. Permanent records may be of research, legal, historical, or scientific value. In the geophysics community, some of the more important permanent records are the surface weather, upper-air, and bathythermograph observation record sheets and recordings taken by our observers. Just as important are research and program development files, and the so-called Trip Reports or Deployment Reports filed by returning Mobile Environmental Team members and Geophysics Officers of the Atlantic and Pacific Fleets. Many Operation and Exercise support files and Command History files from the Oceanography Centers also contain permanent record information. Usually, permanent record material is original material produced by you and the personnel in your office or command, but not all original material is permanent record material.

- *Temporary material*—Informational material that has little long-term value or significance but is necessary for the routine or short-term use. A few examples of temporary material frequently found in the geophysics community are the training reports, inventories, and general correspondence. In general, most material you file that is a *copy* of other material (copies of charts, messages, letters, technical information or magazine articles, and publications or pamphlets) may be considered temporary material.

Files for a specific subject may contain mixed material—both permanent-record information and temporary information. Files that contain predominately permanent-record information are permanent files. Permanent files may contain copies of temporary information that directly relates to the information in the file, or supports the work or research. Temporary files contain mostly temporary information. Any information of permanent value in a temporary file must be separated from the file when the temporary information is destroyed.

Files are normally held in drawers of filing cabinets or safes, and separate file folders are used to contain each subject file. Many different types and grades of file folders are available in the supply system. Use of a specific type of file folder may be designated by the command or left to the user's choice. For ease of finding and retrieving material, however, similar size file folders should be used in each set of files.

Many shipboard geophysics offices and Oceanography Centers/Facilities also originate or receive, and hold, NEDS charts, FNOC message products, AUTODIN message reports of shipboard observations, outgoing meteorological and oceanographic support messages, incoming NWS products and bulletins, facsimile charts, and original (locally produced) meteorological or oceanographic analysis and prognostic charts. Few of these products are routinely stored in what is typically thought of as a set of files. Most likely, the smaller size paper products are sorted by type and date and stored in expandable envelopes, and the larger size original charts and facsimile charts are stored in map drawers or chart cabinets. The products, regardless of the method or location of storage, are official files and must be properly maintained, just as the material kept in file folders in safes and filing cabinets is properly maintained.

Most files are maintained on an annual basis. A separate set of file folders is used for each year's files. Usually, file subject-titles and SSICs are duplicated on the new file folders. While most files start at the beginning of the calender year (January 1) and are closed out at the end of the calender year (December 31), fiscal files (or files dealing with budgeting, supply, or other money matters) are opened at the beginning of the Fiscal Year (1 October) and are closed at the end of each Fiscal Year (September 30). The date that files are closed is known as the *cutoff date*. No new material dated after the cutoff date should be placed in a file after the cutoff date. Material

originated after the cutoff date should be placed in the next year's set of files.

After the cutoff date, files must be held for a prescribed period of time, based on the type of information they hold. This period of time is known as the *retention period*. Most material held in files in geophysics offices have retention periods from 1 to 3 years. To determine the proper retention period for material in your files, you must consult SECNAVINST 5212.5, *Disposal of Navy and Marine Corps Records.*

Tasks Necessary to Maintain a Filing System

The following are some of the more important tasks involved with proper filing system maintenance:

- Inventory the current filing system to ensure the index of your files is up-to-date. For each file you maintain, the index should contain the file subject-title, the SSIC, a specific cutoff date, the retention period, and the transfer or disposal date.

- Obtain some type of receipt from all personnel removing files from the filing cabinet. This will simplify locating files that later turn up missing. The receipt should document the name of the person removing the file, the office or phone number, and an approximate length of time the file will be absent from the storage container. You may use a log book, 3×5 cards, or slips of paper for the receipt, as long as you can keep track of the location of all of your files.

- Ensure all files in your filing system are properly marked with the subject-title, SSIC, and cutoff date, retention period, and the transfer or destroy date.

- Establish new files as necessary.

- Arrange file folders in SSIC order.

- Place incoming information in proper subject files in date/time order, oldest on the bottom. Although the practice is not required, most people maintaining files in the geophysics community prefer to use paper prongs to hold papers securely in each file.

- Close out files at the cutoff date and replace with new file folders (properly labeled) as necessary.

- Keep closed out files together in a safe, weatherproof location. Normally, closed-out files are maintained in the original office if space permits. Maintain closed-out files for the required retention period.

- Destroy temporary material at the end of the retention period. Keep in mind security considerations. Shred, pulp, or burn classified and For Official Use Only material.

- Transfer permanent records to the nearest Federal Records Retention Center in accordance with instructions in SECNAVINST 5212.5 at the end of the retention period.

Learning Objectives: Identify the manual that contains instructions for disposing of records, publications, and files. Identify the length of time different types of meteorological and oceanographic records, publications, and files must be retained.

Disposal of Records and Files

Table 7-1-1 lists different types of meteorological and oceanographic records, identifies the information as permanent or temporary, and lists the retention periods of the information as defined in SECNAVINST 5212.5C (as of 13 February 1989).

Permanent records, with the exception of observation records, should be transferred to the Federal Records Center after the retention period has passed. Specific instructions for handling the transfer of meteorological and oceanographic observation records to the Climatic Records Center in Asheville, North Carolina, are provided in NAVOCEANCOMINST 3140.1, *U.S. Navy Oceanographic & Meteorological Support System Manual.*

Temporary records and files should be properly disposed of or destroyed after the retention period has elapsed.

MAINTAINING DIRECTIVES

All Naval Oceanography Command units and all naval ships with Aerographer's Mates receive and are required to maintain directives issued by the Commander, Naval Oceanography

Table 7-1-1.—Retention Requirements for Meteorological and Oceanographic Records and Information

DESCRIPTION OF INFORMATION OR RECORD	TYPE	RETENT. PERIO
General correspondence concerning meteorology, climatology, or oceanography originated or received by an Oceanographic Center.	Temporary	3 years
General correspondence concerning meteorology, climatology, or oceanography originated or received by an Oceanographic Facility or Detachment.	Temporary	2 years
Original charted products (or magnetic/laser storage media copy) produced by the Oceanographic Centers.	Permanent	1 year
Original charted products (or magnetic/laser storage media copy) produced by Oceanographic Facilities or Detachments.	Temporary	1 year
Facsimile copies of charted products received ashore or aboard ship.	Temporary	1 month
Meteorological and oceanographic observation records and recordings.	Permanent	1 month
Duplicate copies of meteorological and oceanographic observation and recordings.	Temporary	until no lo needed for erence
All meteorological and oceanographic data received over dedicated meteorological/oceanographic broadcasts such as the Fleet Multi-channel Broadcast, COMEDS/PACMEDS/CARMEDS, or Air Force regional HF broadcasts.	Temporary	1 month until no lo needed
Meteorological and oceanographic observations received via AUTODIN, phone, light, or semaphore from other units.	Temporary	3 months until no lo needed
DD 175-1 Flight Weather Briefings (duplicates).	Temporary	6 months
Meteorological/oceanographic forecasts, warnings, or advisories issued.	Temporary	1 year
Small Craft, Gale, and Storm Warnings issued.	Temporary	6 months
Duplicate copies of any meteorological or oceanographic records or communications relating to distress, accident, or mishap of a vessel or aircraft, or relating to any military accident or injury investigation.	Temporary	3 years

Command. Aboard ships, the instructions are sometimes maintained in the ship's Administration Office, but more often than not, they are maintained in the Geophysics Office.

You will also need to maintain selected instructions from the Office of the Secretary of the Navy (SECNAV), Bureau of Naval Personnel (BUPERS), Office of the Chief of Naval Operations (OPNAV), and Commander in Chief, Atlantic (or Pacific) Fleet (CINCLANTFLT). At the Naval Oceanography Command Centers and Facilities, you will also maintain a set of your center's or facility's directives.

Most of the instructions and notices your office maintains are only a few pages long. Others may be 1- or 2-inch-thick manuals. Usually, all but the thickest directives are placed in standard government-issue three-ring binders, and stored in some type of bookcase. With the exception of certain classified instructions, which must be stored in a secure container, all instructions from a series should be kept together. The binders should be labeled so that the other people you work with can find the instructions easily.

All directives within a set are arranged in SSIC order, from the lowest number to the highest number.

The first task you must do when you are assigned the job of maintaining any set of directives is to inventory the instructions and notices currently onboard, making note of any that seem to be missing. The two directives previously discussed, NAVOCEANCOMNOTE 5215 and NAVPUBINST 5215.1, list effective instructions. A quick look around the spaces may turn up several of the most frequently used instructions that were missing. Also check that over-flowing *incoming* basket on your desk (or the LPO's desk) to insure that the missing directives are not in-house, awaiting filing.

If a directive is normally held in some other location than the directives binder, a *locator cross-reference sheet* should be filled in and filed in the location the directive would normally occupy in the binder. Most manual-like directives contain a preprinted locator cross-reference sheet immediately following the distribution list in the front of the instruction.

Sign-out cards or some similar system should be used when directives are temporarily removed from the binders for any reason.

Make note of any instructions that are obsolete. If the manual lists 3143.1D as the current instruction and you have 3143.1C, you will need to obtain 3143.1D. Identify the 3143.1C edition in the binder as being obsolete by writing *superseded by 3143.1D* across the top of the first page in dark colored ink. Do not destroy the old instruction until you have received the updated version. Many times, much of the information in the old instruction will still be valid.

Order any instructions that you are missing. NAVPUBINST 5215.1 marks all instructions that are available directly from the originator with an asterisk (*). All others must be ordered from the Naval Publications and Forms Center via normal supply channels. NAVPUBINST 5215.1 provides instructions for ordering all stocked publications. The microfiche publication, NPFC 2002 (Naval Publications and Forms Center publication 2002), Section 4, lists stock numbers for all instructions stocked by the Naval Publications and Forms Center. Section 4 is arranged alphabetically by command, with instructions issued by each command arranged numerically by SSIC.

As you receive new or updated directives, file the directives in their proper locations in the binder by SSIC. Remove and destroy the outdated directives.

Many instructions are updated with change transmittals. Change transmittals identify the instruction to which they apply, and list several types of changes that must be made to the instruction to update it. Many times, change transmittals will contain replacement pages, which must be inserted in the place of the old same-numbered pages in the instruction. These are *page changes*.

Change transmittals may also list words or passages that must be entered in pen in specified places. These are called *pen changes*.

Occasionally, a change transmittal will contain a printed paragraph and will call for the new paragraph to be cut out of the change and taped or pasted over an existing paragraph in the instruction. This is called a *paste-in change*.

Another type of change that may be used is a *repetitive change*. This type of change is usually a blanket statement such as *replace the words Naval Weather Service with Naval Oceanography throughout the instruction*. This type of change does not specify the location of the required changes. Unless specifically stated otherwise, repetitive changes are not actually made throughout the instruction. The change transmittal

containing the repetitive change is filed at the beginning of the basic instruction; the repetitive change statement may be highlighted to catch the reader's eye.

Regardless of the number of changes specified, you must follow the list of change instructions exactly as described. We strongly recommend that you check off each change instruction as you complete the change. Changes should be entered in the appropriate instructions as soon as change transmittals are received, and should not be shunted to a hold basket to collect dust. Changes should be made to all copies of the instructions held, not just the copy normally held in the binder. Usually, the changes listed in change transmittals are effective as of the publishing date (the date listed on the transmittal), and will have been in effect for several weeks by the time you receive the change transmittal.

After the necessary changes have been made to the instruction, you must enter the change information on the *Record of Changes* page, located in the front of most instructions. This page, ruled in columns and lines, requires entries of (1) the change number (change 1 or CH1, for example), (2) the date the change was issued, (3) the date the change was actually entered, and (4) the name (not initials) and rate of the person entering the change.

In summary, in order to properly maintain a set of directives, you must accomplish the six tasks we have just discussed:

- INVENTORY all directives, making note of missing or out-of-date directives.

- ORDER replacements for missing or obsolete directives.

- FILE new and revised directives as they are received.

- ENTER CHANGES documented in change transmittals, as they are received.

- COMPLETE locator cross-reference sheets for all directives held in locations other than the proper directives binder.

- Use a SIGN-OUT system for all borrowed directives.

Learning Objectives: Identify the manuals that list the publications and forms required by activities supporting various meteorological and oceanographic functions. Identify the source manuals for information about climatic publications and summaries.

MAINTENANCE OF METEOROLOGICAL AND OCEANOGRAPHIC PUBLICATIONS

So far, we have discussed maintenance of files and directives. Two other administrative functions you may be asked to do are to maintain meteorological and oceanographic reference publications, and to maintain meteorological and oceanographic forms. Many of the NOC Centers and Facilities have a billet for an AG2 to be specifically designated as the Command Librarian or the Records Petty Officer. Maintenance of meteorological and oceanographic forms is a small task and is usually done by the operations assistant, sometimes an AG2.

As you have probably discovered, every Geophysics Office, whether aboard ship or ashore, has many different reference publications available for use. Some offices routinely receive and maintain specialized magazines dealing with the sciences of meteorology and oceanography, such as *Weatherwise* or *Bulletin of the American Meteorological Society*. Nearly every Naval Oceanographic Command activity and every shipboard Geophysics Office was issued many different NAVAIR publications. These are books published by the government or civilian publishing companies that the Naval Air Systems Command determined to be useful for reference. Other publications you might have in your office are equipment technical manuals and operator manuals that were issued with various pieces of equipment or with equipment systems.

We can classify all the various types of publications into three groups: Required Publications, Allowed Publications, and useful publications.

Required Publications

Required publications are the hard- or soft-covered books that you must have on hand, as

Table 7-1-2.—Required Publications for Meteorological and Oceanographic Support Activities

	NAVAIR	AIR FIELD SUMMARIES	SSMOs	NAVOCEANO OCEANOGRAPHIC PUBLICATIONS
FLENUMOCEANCEN/NAVOCEANO	1	1	1	1
NAVOCEANCEN/NAVOCEANCOMCEN	1	1	1	1
NAVOCEANCOMFAC	1	1	2	2
NAVOCEANCOMDET/MCAS	3	2	2	3
NAVOCEANCOMDET (without operational forecast services)	3	3	3	3
Afloat Geophysics Units*	3	1	2	2
Marine Aircraft Group	3	2	2	3
Marine Aircraft Wing	3	3	3	3

Explanation:

1 - A complete set of the publications must be maintained or be locally accessible by the activity.

2 - Only those publications dealing with the activity's Area of Responsibility must be maintained or be locally accessible by the activity.

3 - Publications are not required to be held by the activity.

* Oceanographic Publications requirements are established in appropriate PACFLT/LANTFLT directives.

directed by proper authority. Required publications for shore Navy and Marine Corps Meteorological or Oceanographic support activities are defined in NAVOCEANCOMINST 5605.2, *Meteorological and Oceanographic Publications, Charts, and Forms; requirements and distribution*. In addition, this instruction provides information on the source of each of the many different publications used by Aerographers; the agency responsible for updating the publication; and the agency that publishes and distributes each type of publication. The instruction also lists the meteorological and oceanographic forms that are stocked by the Naval Publications and Forms Center, Philadelphia. Table 7-1-2, extracted from the instruction, defines the few *required* publications. The only publications directly addressed are NAVAIR publications, Air Field Summaries, SSMOs (Summaries of Synoptic Meteorological Observations), and Naval Oceanographic Office publications.

Source listings for NAVAIR publications, Airfield Summaries, and SSMOs are discussed in the following paragraphs. Unclassified Naval Oceanographic Office publications are listed in the *Catalog of Naval Oceanographic Office Publications*, NAVOCEANO SP 3-P. Classified Naval Oceanographic Office publications are listed in the *Catalog of Classified Naval Oceanographic Office Publications*, NAVOCEANO SP 3-P(S).

Allowed Publications

NAVAIR 00-35QL-22, NAVAIR Allowance List, *Meteorological Equipment for Navy Meteorological Units*[1], lists allowances for equipment, publications, and forms for various types

[1]The next Section L will be issued as a SPAWAR (Space Warfare Command) publication

of meteorological support functions. The items and quantities listed are the maximum that are allowed to be held by a ship or shore activity. The inclusion of a specific publication title in the allowance listing does not mean that every ship or station must maintain that particular publication; it means if that publication is necessary, only the specific quantity indicated should be ordered. Most publications listed have the allowances set at one copy of each particular publication.

Since NAVAIR foots the bill for the initial outfitting of a unit, if you desire two copies of a particular publication but the NAVAIR allowance is only one copy, you may order the second copy but it must be paid for by your ship or station, not by NAVAIR. If a particular publication is not included as in the allowance listing, it does not mean that you are not allowed to have a copy of that particular publication.

The *Section L* listing of allowed publications includes a few items that would not normally be thought of as publications, such as plastic overlays (the refractive overlay for a Skew T, Log P Diagram) and printed graphs/diagrams (horizontal-distance-out scales used in upper-air observations). It also includes at least one Naval Oceanography Command Instruction.

If your activity is required to maintain NAVAIR publications, the *Section L* allowance list contains a complete listing of the NAVAIR publication you should have.

Useful Publications

Appendix V of NAVOCEANCOMINST 3140.1, *U.S. Navy Oceanographic & Meteorological Support System Manual*, lists pertinent references for oceanographic and meteorological support. These consist of different instructions and publications that contain information especially useful for different geophysics-related jobs and situations. However, the appendix stresses that the list is not a list of required publications.

NAVOCEANCOMINST 5605.2 also provides a listing of useful publications for meteorology and oceanography.

Sources of Information About Climatic Publications

The National Weather Service, the Air Force, and the Navy all produce various types of climatic studies and climatic summaries. Many of these products are routinely distributed to your command as they are produced. Some products must be specifically ordered. The best guide to find what types of climatic information are available for a specific location or for an area is the publication *Guide to Standard Weather Summaries*, NA 50-1C-534. This publication lists various cities around the world, and indicates what types of climatic summaries are available. It does not list any classified studies that may have been made for any particular location. The only drawback to this publication is that new areas and revised studies are being done every year but the Guide has not been revised for several years now.

NOCD Asheville publishes an annual report listing all of the climatic studies that have been published by the Navy and are currently available for issue on different types of media—paper, microfiche, microfilm, floppy diskette, or Compact Disk (Read Only Memory). This listing, issued as NOCD ASHEVILLENOTE 3146, *Atmospheric Climatic Publications* (formerly *Climatic Publications Prepared by the Naval Oceanography Command Detachment Asheville for the Commander, Naval Oceanography Command*) is updated annually, and it is an excellent index for naval climatic publications.

If your activity is required to maintain a full or partial set of *Airfield Summaries* (or *SSMOs*), NOCD ASHEVILLENOTE 3146 contains a complete listing of the separate volumes and areas they cover.

The Air Force, which also publishes many climatic studies each year, issues a catalog that lists the locations covered by Air Weather Service climatic studies or summaries and that lists the type(s) of studies available. This is the *Catalog of Air Weather Service Technical Documents*, AWS/TC-89/001. This catalog not only is an excellent index for AWS climatic summaries and studies, but it also lists the Navy's climatic studies and summaries, as well as many other technical publications on meteorology-related topics. This catalog is updated annually, but has distribution and use limited to For Official (government) Use Only. Copies of the publication may be requested (by Naval activities) through the Commander, Naval Oceanography Command.

Maintenance of Publications

So far we have discussed some sources that list publications that may be found in your office. Now we will discuss how to take care of the publications that you have.

The Naval Oceanography Command Centers and Facilities may have rooms that are designated as a library, but for most Detachments and ships, this is a luxury that is not permitted, because of space limitations. Undoubtedly, you have some bookcase space available, whether aboard ship, in a detachment, or at a center or facility. If your command has an established system for filing and retrieving publications, and the system generally works, then the best thing you can do is to learn that system and work with it.

If no workable system has been established, the simplest system for office-size book collections is the alphabetical filing system. File the publications on shelves in alphabetical order by the title. Index cards (or a computer listing) should be made up for each book, listing the title, publication number, and subject(s) covered. These cards should be held in a filing box, alphabetically by title. If time and resources permit, an additional set of cards should be made and filed by subject in a separate box or separate section of the card file box (or in a separate file in your computer).

For slightly larger collections of publications, you may wish to divide the bookcase shelves into sections for each series of publications, such as NAVAIR publications (all publications with NAVAIR numbers), Air Weather Service Publications, National Weather Service Publications, Naval Oceanographic Office publications, Naval Environmental prediction Research Facility publications, and so forth. Publications within each group may be arranged alphabetically. The same type of index card title and subject lists may be maintained, but each card should also include a listing of the bookcase section in which the publication is located.

Only the larger, full-room-size libraries may justify the extra work required to cross-reference title, subject, and author indexes, and mark bindings with the standard Dewey Decimal Library System code. If this system is selected, consult your local base library for further information.

Your title index and subject index are the key to your library. Keep the index current. Let the other people you work with know how the publications are arranged and how the index is maintained. If the index is maintained on the office computer, let them know how to access the information, or be available to access the information for them.

Some sort of check-out log or system must be used to keep track of publications that are removed from the area. The most useful reference publications, if not controlled properly, tend to "disappear" from libraries. These publications may sometimes be located on someone's desk; but without a check-out system, larger commands must reorder publications frequently.

As for the publications themselves, all books should be kept in a dry, low-humidity environment. High-humidity and moisture promote mold growth, which destroys the paper. Books should not be stored exposed to strong or direct sunlight. Sunlight yellows the edges of the pages and accelerates paper decomposition. It also makes the binding become brittle.

Aboard ship, it is common practice to box up and store publications that are not expected to be especially useful during an upcoming cruise, in an out-of-the-way location. The index cards or computer index of books stored in this manner should be annotated with the storage location.

Learning Objective: Identify the source manual for information about various meteorological and oceanographic charts.

MAINTENANCE OF PLOTTING CHARTS

While the use of Department of Defense Weather Plotting Charts has been on a steady decline since the introduction of computers into the weather business, the Navy geophysics community will continue to hand-plot weather charts in the immediate future. The ships that normally carry AGs, and all of the shore activities, have established requirements for weather-plotting charts. Most shore stations and many ships have signed up, in the past, for automatic distribution of certain weather plotting charts. With automatic distribution, pre-designated quantities of each type of chart are automatically forwarded to the ship or activity on a monthly, quarterly, or annual basis.

During pre-deployment chart inventories aboard ship, and during regular annual inventories ashore, a count of the type and quantity of weather-plotting charts is usually made. Based on the past usage of each chart, the monthly usage of each type of chart should be calculated. Shipboard personnel must estimate monthly usage of each type of chart that may be necessary for several different contingencies. Charts not

normally used in routine operations may be especially important in different operational scenarios. Consult your Division Chief or Division Officer, who may be familiar with the ships classified contingency plans, for chart requirements.

All ships and stations should keep a 90-day supply of plotting charts on hand. However, decreased usage of many charts, along with automatic distribution, has resulted in an accumulation of several years' usage of plotting charts on hand in many cases.

When you are tasked to maintain your command's stock of weather-plotting charts, inventory the quantity of each type of plotting chart. After inventory, carefully calculate the usage of each chart during the past year, and determine how long current quantities on hand will last. If you have more than a 90-day supply, consider suspending or amending automatic-distribution requirements.

Detailed instructions for establishing or changing automatic distribution requirements and for completing a one-time order of weather-plotting charts are contained in the *Department of Defense, Defense Mapping Agency Catalog of Maps, Charts, and Related Products*, Part 1 - Aerospace Products, Volume II, *Weather Plotting Charts*. Currently there are 7 parts and 30 volumes to the complete DMA catalog. Your command may maintain only Part 1, Volume II, or it may maintain the entire catalog.

Review the catalog if you have a chance. You will find that many of the products listed in Part 2 - Hydrographic Products and in Part 3 - Topographic Products are essential in calculating certain meteorological and oceanographic forecasts.

SUMMARY

In this lesson we have discussed some basic knowledge you must have to accomplish the administrative tasks of maintaining files, records, directives, publications, and plotting charts. As an Aerographer's Mate Second Class, you will be asked to do these tasks from time to time.

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APPENDIX I

GLOSSARY

ABSOLUTE INSTABILITY—The state of a column of air in the atmosphere when it has a superadiabatic lapse rate of temperature. An air parcel displaced vertically would be accelerated in the direction of the displacement.

ABSOLUTE STABILITY—The state of a column of air in the atmosphere when its lapse rate of temperature is less than the saturation adiabatic lapse rate. An air parcel will be more dense than its environment and tend to sink back to its level of origin.

ABSORPTION—The process in which incident radiant energy is retained by a substance.

ADVECTION—The horizontal transport of an atmospheric property solely by the mass motion (velocity field) of the atmosphere.

ADVECTION FOG—Fog caused by the advection of moist air over a cold surface, and the consequent cooling of that air to below its dew point.

AIR MASS—A widespread body of air that is approximately homogeneous in its horizontal extent, with reference to temperature and moisture.

ALBEDO—The ratio of the amount of electromagnetic radiation reflected by a body to the amount incident upon it.

ANABATIC WIND—An upslope wind; usually applied only when the wind is blowing up a hill or mountain as the result of surface heating.

ANTARCTIC FRONT—The semipermanent, semicontinuous front between the antarctic air of the Antarctic Continent and the polar air of the southern oceans; generally comparable to the arctic front of the Northern Hemisphere.

ANTICYCLOGENESIS—The strengthening or development of an anticyclonic circulation in the atmosphere.

ANTICYCLOLYSIS—The weakening of an anticyclonic circulation in the atmosphere.

ANTICYCLONE—A closed circulation in the atmosphere that has a clockwise rotation in the Northern Hemisphere and a counterclockwise rotation in the Southern Hemisphere. Used interchangeably with high.

ANTICYCLONIC—Refers to the rotation pattern of anticyclones. See ANTICYCLONE.

ARCTIC FRONT—The semipermanent, semicontinuous front between the deep, cold arctic air and the shallower, basically-less-cold polar air of northern latitudes; generally comparable to the antarctic front of the Southern Hemisphere.

AUTOCONVECTIVE LAPSE RATE—The temperature lapse rate in an atmosphere where density is constant with height.

BACKING—A change in wind direction in a counterclockwise manner in the Northern Hemisphere and in a clockwise manner in the Southern Hemisphere.

BLOCKING HIGH—An anticyclone that remains stationary or moves slowly westward so as to effectively block the movement of migratory cyclones across its latitudes.

BRIGHT BAND—As seen on a range-height indicator, the enhanced radar echo of snow as it melts to rain. The freezing level can normally be found approximately 1,000 feet above this band.

BUYS BALLOT'S LAW—The law describing the relationship of horizontal wind direction to pressure: In the Northern Hemisphere, with your back to the wind, the lowest pressure will be to your left; in the Southern Hemisphere, to your right.

CENTER OF ACTION—Any one of the semipermanent high- or low-pressure systems.

CENTRAL PRESSURE—The atmospheric pressure at the center of a high or low; the highest pressure in a high, the lowest in a low.

CHROMOSPHERE—A thin layer of relatively transparent gases above the photosphere of the Sun.

CLOSED HIGH—A high that is completely encircled by an isobar or contour line.

CLOSED LOW—A low that is completely encircled by an isobar or contour line.

COLD-CORE HIGH—Any high that is generally characterized by colder air near its center than around its periphery at a given level in the atmosphere.

COLD-CORE LOW—Any low that is generally characterized by colder air near its center than around its periphery at a given level in the atmosphere.

CONDENSATION—The physical process by which a vapor becomes a liquid or solid.

CONDITIONAL INSTABILITY—The state of a column of air in the atmosphere when its temperature lapse rate is less than the dry adiabatic lapse rate but greater than the saturation adiabatic lapse rate.

CONTOURS—Term referring to constant-height lines on a constant-pressure chart. Used interchangeably with *isoheights*. Each line represents a line of constant elevation above a certain reference level (usually mean sea level).

CONVECTION—Atmospheric motions that are predominantly vertical, resulting in the vertical transport and mixing of atmospheric properties.

CORONA—(1) A set of one or more prismatically colored rings of small radii, concentrically surrounding the disk of the Sun, Moon, or other luminary when veiled by a thin cloud. A corona may be distinguished from the relatively common 22° halo by its color sequence, which is from blue inside to red outside, the reverse of that of the 22° halo. Coronas are produced by diffraction and reflection of light from water droplets. (2) The pearly outer envelope of the Sun.

COUNTERRADIATION—(also called *back radiation*) The downward flow of atmospheric radiation passing through a given level surface, usually taken as Earth's surface. It is the principal factor in the GREENHOUSE EFFECT.

CUT-OFF HIGH—A warm high displaced and lying poleward of the basic westerly current.

CUT-OFF LOW—A cold low displaced and lying equatorward of the basic westerly current.

CYCLOGENESIS—Any development or strengthening of cyclonic circulation in the atmosphere. The initial appearance of a low or trough, as well as the intensification of an existing cyclonic flow.

CYCLOLYSIS—Any weakening of cyclonic circulation in the atmosphere.

CYCLONIC—A counterclockwise rotation in the Northern Hemisphere and a clockwise rotation in the Southern Hemisphere.

DEEPENING—A decrease in the central pressure of a low-pressure system.

DISPERSION—The process in which radiation is separated into its component wavelengths. It results when an optical process, such as diffraction, refraction, or scattering, varies according to wavelength. All of the coloration displayed by atmospheric optical phenomena is the result of dispersion.

DIURNAL—Any change that follows a daily pattern, completing one cycle each day.

DIURNAL TIDE—A tidal cycle that has one high- and one low-tide stage each day.

DOLDRUMS—A nautical term for the equatorial trough, with special reference to the light and variable nature of the winds.

DOWNWIND—The direction toward which the wind is blowing; with the wind.

DROPSONDE—A radiosonde that is dropped by parachute from an aircraft for the purpose of obtaining a sounding of the atmosphere below.

DRY AIR—In atmospheric thermodynamics and chemistry, air that contains no water vapor.

DYNAMIC TROUGH—(also called *lee trough*) A pressure trough formed on the lee side of a mountain range across which the wind is blowing almost at right angles; often seen, on U.S. weather maps, east of the Rocky Mountains, and sometimes east of the Appalachians, where it is less pronounced.

EASTERLIES—Any winds with components from the east, usually applied to broad currents or patterns of persistent easterly winds; the "easterly belts," such as the equatorial easterlies, the tropical easterlies (trade winds), and the polar easterlies.

EASTERLY WAVE—A migratory wave-like disturbance of the tropical easterlies. Easterly waves occasionally intensify into tropical cyclones.

ECM—Electronic countermeasures.

EDDY—A rotating vortex in a liquid or gas caused by frictional forces or by the interference of an obstacle.

ELECTROMAGNETIC WAVES—Disturbances in electric and magnetic fields in space or in material media, resulting in the propagation of electromagnetic energy (radiation).

EQUATORIAL TROUGH—The quasi-continuous belt of low pressure lying between the subtropical high-pressure belts of the Northern and Southern hemispheres. The region is one of very homogeneous air, probably the most ideally barotropic region of the atmosphere. The position of the equatorial trough is fairly constant in the eastern portions of the Atlantic and Pacific, but it varies greatly in the western portions of those oceans and in southern Asia and the Indian Ocean. It moves into or toward the hemisphere experiencing summer.

EQUINOX—(1) Either of the two points of intersection of the Sun's apparent annual path and the plane of Earth's equator. (2) Popularly, the time at which the Sun passes directly above the equator; the "time of the equinox." In the Northern Hemisphere, the vernal equinox falls on or about 21 March, and the autumnal equinox on or about 22 September. These dates are reversed in the Southern Hemisphere.

ETAGE—The layers of the atmosphere by which the different types of clouds are identified. The Low Etage clouds are from the surface to 6,500 feet, the Mid Etage clouds from 6,500 feet to 18,000 feet, and the High Etage clouds are above 18,000 feet.

EVAPORATION—The physical process by which a liquid or solid is transformed into the gaseous state.

EXTRATROPICAL CYCLONE—Typically, any cyclonic-scale storm that forms poleward of the tropical easterlies, i.e., the migratory frontal cyclones. Tropical cyclones that move poleward out of the tropical easterlies and take on extratropical characteristics (air mass discontinuity) are reclassified as extratropical.

FILLING—An increase in the central pressure of a pressure system on a constant-height chart, or an analogous increase in height on a constant-pressure chart; the opposite of *deepening*.

FRONT—The interface or transition zone between two air masses of different density. Since temperature distribution is the most important regulator of atmospheric density, a front almost invariably separates air masses of different temperature.

FRONTAL INVERSION—A temperature inversion in the atmosphere, encountered upon vertical ascent through a sloping front.

FRONTAL SURFACE—Refers specifically to the warmer side of the frontal zone.

FRONTAL SYSTEM—Simply, a system of fronts as they appear on a synoptic chart. This is used for (a) a continuous front and its characteristics along its entire extent, including its warm, cold, stationary, and occluded sectors, its variations of intensity, and any frontal cyclones along it; and (b) the orientation and nature of the fronts within the circulation of a frontal cyclone.

FRONTAL ZONE—The transition zone between two adjacent air masses of different densities bounded by a frontal surface.

FRONTOGENESIS—The initial formation of a front or frontal zone.

FRONTOLYSIS—The dissipation of a front or frontal zone.

GENERAL CIRCULATION—(also called *planetary circulation*) In its broadest sense, the complete statistical description of atmospheric motions over Earth.

GEOPOTENTIAL—The potential energy of a unit mass relative to sea level, numerically equal to the work that would be done in lifting the unit mass from sea level to the height at which the mass is located; commonly expressed in terms of *dynamic height* or *geopotential height*.

GEOPOTENTIAL HEIGHT—The height of a given point in the atmosphere in units proportional to the potential energy of a unit mass (geopotential) at that height, relative to sea level.

GEOSTROPHIC FLOW—A form of gradient flow where the Coriolis force exactly balances the horizontal pressure force.

GEOSTROPHIC WIND—That horizontal wind velocity for which the Coriolis acceleration exactly balances the horizontal pressure force. The geostrophic wind is directed along the contour lines on a constant-pressure surface (or along the isobars in a geopotential surface) with low pressure to the left in the Northern Hemisphere and to the right in the Southern Hemisphere.

GEOSTROPHIC-WIND SCALE—A graphical device used for the determination of the speed of the geostrophic wind from the isobar or contour-line spacing on a synoptic chart.

GRADIENT—The space rate of decrease of a function. It is often used to denote the magnitude of pressure change in the horizontal pressure field.

GRADIENT WIND—Any horizontal wind velocity tangent to the contour line of a constant-pressure surface (or the isobar of a geopotential surface) at the point in question. At such points, where the wind is gradient, the Coriolis acceleration and centripetal acceleration together exactly balance the horizontal pressure force.

GRAVITY WIND—(also called *drainage wind*; sometimes called *katabatic wind*) A wind (or component thereof) directed down the slope of an incline and caused by greater air density near the slope (caused by surface cooling) than at the same levels some distance horizontally from the slope.

GREENHOUSE EFFECT—The heating effect exerted by the atmosphere upon Earth by virtue of the fact that the atmosphere (mainly, its water vapor) absorbs and re-emits infrared radiation. In detail: the shorter wavelengths of insolation are transmitted rather freely through the atmosphere to be absorbed at Earth's surface. Earth then re-emits this as long-wave (infrared) terrestrial radiation, a portion of which is absorbed by the atmosphere and again emitted as atmospheric radiation. The water vapor (cloud cover) acts in the same way as the glass panes of a greenhouse; the heat gained during the day is trapped beneath the cloud cover, and the counter-radiation adds to the warming of Earth.

GROUND CLUTTER—The pattern of radar echoes from fixed ground targets near the radar. This type of clutter tends to hide or confuse the echoes returned from nearby moving or precipitation targets. Ground clutter can be significantly increased during periods of superrefraction.

HALO—Any one of a large class of atmospheric optical phenomena (luminous meteors) that appear as colored or whitish rings and arcs about the Sun or Moon when seen through an ice-crystal cloud or in a sky filled with falling ice crystals. The halos experiencing prismatic coloration are produced by refraction of light by the ice crystals, and those exhibiting only whitish luminosity are produced by reflection from the crystal faces.

HEAT BALANCE—The equilibrium, which exists on the average, between the radiation received by Earth and its atmosphere and that emitted by Earth and its atmosphere.

HEAT TRANSFER—The transfer or exchange of heat by radiation, conduction, or convection in a fluid and/or between the fluid and its surroundings. The three processes occur simultaneously in the atmosphere, and it is often difficult to assess the contributions of their various effects.

HEATING DEGREE-DAY—A form of degree day used as an indication of fuel consumption; in United States usage, one heating degree-day is given for each degree that the daily mean temperature departs below the base of 65 °F.

HECTOPASCALE—The standard unit of force used in atmospheric pressure measurements. This term has officially replaced the term *millibars.* 1 hectopascale is exactly equal to 1 millibar.

HIGH—An "area of high pressure," referring to a maximum of atmospheric pressure in two dimensions (closed isobars) on the synoptic surface chart, or a maximum of height (closed contours) on the constant-pressure chart. Highs are associated with anticyclonic circulations, and the term is used interchangeably with *anticyclone.*

HIGH ZONAL INDEX—A relatively high value of the zonal index, which in middle latitudes indicates a relatively strong westerly component of wind flow and the characteristic weather features attending such motion. A synoptic circulation pattern of this type is commonly called a "high-index situation".

HORSE LATITUDES—The belts of latitude over the oceans at approximately 30 to 35 degrees north and south where winds are predominantly calm or very light and the weather is hot and dry.

HURRICANE—A severe tropical cyclone in the North Atlantic Ocean, Caribbean Sea, Gulf of Mexico, and in the eastern North Pacific, off the west coast of Mexico.

ICELANDIC LOW—The low-pressure center located near Iceland (mainly between Iceland and southern Greenland) on mean charts of sea-level pressure. It is a principal center of action in the atmospheric circulation of the Northern Hemisphere.

INACTIVE FRONT—(or passive front) A front or portion thereof that produces very little cloudiness and no precipitation, as opposed to an active front.

INFERIOR MIRAGE—A spurious image of an object formed below the true position of that object by abnormal refractive conditions along the line of sight; one of the most common of all types of mirage, and the opposite of a *superior mirage.*

INFRARED RADIATION—Electromagnetic radiation lying in the wavelength interval from about 0.8 micron to an indefinite upper boundary, sometimes arbitrarily set at 1,000 microns. On the lower side of the electromagnetic spectrum, it is bounded by visible radiation, whereas on the upper side it is bounded by microwave radiation.

INSOLATION—(contracted from *incoming solar radiation*) In general, solar radiation received at Earth's surface.

INSTABILITY—A property of the steady state of a system such that certain disturbances or perturbations introduced into the steady state will increase in magnitude, the maximum perturbation amplitude always remaining larger than the initial amplitude.

INSTABILITY LINE—Any non-frontal line or band of convective activity in the atmosphere.

INTERTROPICAL CONVERGENCE ZONE—The axis or a portion thereof, of the broad trade-wind current of the tropics. This axis is the dividing line between the southeast trades and the northeast trades (of the Southern and Northern hemispheres, respectively).

INTERTROPICAL FRONT—A front presumed to exist within the equatorial trough separating the air of the Northern and Southern hemispheres. However, this front cannot be explained in the same terms as those of the fronts of higher latitudes.

INVERSION—The departure from the usual decrease or increase with altitude of the value of an atmospheric property. The layer through which this departure occurs is known as the inversion layer, and the lowest altitude at which the departure is found is known as the base of the inversion. The term is almost always used in reference to temperature, but may be applied to moisture and precipitation.

ISALLOBAR—A line of equal change in atmospheric pressure during a specified time interval; an isopleth of equal pressure tendency. Positive and negative isallobars are sometimes referred to as anallobars and katallobars, respectively.

ISOBAR—A line of equal or constant pressure; an isopleth of pressure.

ISOBARIC—Of equal or constant pressure, with respect to either space or time.

ISODROSOTHERM—A line of equal dew-point temperatures.

ISOECHO—A line of equal radar reflectivity.

ISOHEIGHT—See CONTOUR.

ISOHUME—A line of equal humidity.

ISOHYET—A line drawn through geographical points recording equal amounts of precipitation during a given period or for a particular storm. A line of equal precipitation.

ISOLINE—Any line of equal value. See also ISOPLETH.

ISOPLETH—A line of equal or constant value of a given quantity, with respect to either space or time.

ISOPYCNIC LEVEL—Specifically, a level surface in the atmosphere, at about an 8-kilometer altitude, where the air density is approximately constant in space and time.

ISOTACH—A line in a given surface connecting points of equal wind speed.

ISOTHERM—A line of equal or constant temperature.

ISOTHERMAL—Of equal or constant temperature with respect to either space or time.

JET—A common abbreviation for jet stream.

JET STREAM—Relatively strong winds concentrated within a narrow quasi-horizontal stream in the atmosphere. These winds are usually embedded in the mid-latitude westerlies and concentrated in the high troposphere.

KATABATIC WIND—Any wind blowing down an incline; the opposite of anabatic wind. If the wind is warm, it is called a *foehn*; if cold, it may be a *fall* or *gravity wind*.

KINETIC ENERGY—The energy that a body possesses as a consequence of its motion, defined as the product of one-half of its mass and the square of its speed, $1/2mv^2$.

LAND BREEZE—A coastal breeze blowing from land to sea, caused by the temperature difference when the sea surface is warmer than the adjacent land.

LAPSE RATE—The decrease of an atmospheric variable with height, the variable being temperature unless otherwise specified.

LATERAL MIRAGE—A very rare type of mirage in which the apparent position of an object appears displaced to one side of its true position.

LIGHT—Visible radiation (about 0.4 to 0.7 micron in wavelength) considered in terms of its luminous efficiency.

LONG WAVE—A wave in the major belt of westerlies that is characterized by large length and significant amplitude. The wavelength is typically longer than that of the rapidly moving individual cyclonic and anticyclonic disturbances of the lower troposphere. (Compare SHORT WAVE.)

LOOMING—A mirage effect produced by greater-than-normal refraction in the lower atmosphere, thus permitting objects to be seen that are usually below the horizon.

LOW—An "area of low pressure," referring to a minimum of atmospheric pressure in two dimensions (closed isobars) on a constant-height chart or a minimum of height (closed contours) on a constant-pressure chart. Lows are associated with cyclonic circulations, and the term is used interchangeably with cyclone.

LOW ZONAL INDEX—A relatively low value of the zonal index, which in middle latitudes indicates a relatively weak westerly component of wind flow (usually implying stronger north-south motion), and the characteristic weather attending such motion. A circulation pattern of this type is commonly called a "low-index situation."

LOWER ATMOSPHERE—Generally and quite loosely, that part of the atmosphere in which most weather phenomena occur (i.e., the troposphere and lower stratosphere).

MACROCLIMATE—The general large-scale climate of a large area or country, as distinguished from mesoclimate and microclimate.

MAGNETIC NORTH—At any point on Earth's surface, the horizontal direction of Earth's magnetic lines of force (direction of a magnetic meridian) toward the north magnetic pole, i.e., a direction indicated by the needle of a magnetic compass. Because of the wide use of the magnetic compass, magnetic north, rather than TRUE NORTH, is the common 0° (or 360°) reference in much of navigational practice, including the designation of airport runway alignment.

MANDATORY LEVEL—One of several constant-pressure levels in the atmosphere for which a complete evaluation of data derived from upper-air observations is required. Currently, the mandatory pressure values are 1,000 millibars (mb), 850 mb, 700 mb, 500 mb, 400 mb, 300 mb, 200 mb, 150 mb, 100 mb, and 50 mb. The radiosonde code has specific blocks reserved for these data.

MARITIME AIR—A type of air whose characteristics are developed over an extensive water surface and which, therefore, has the basic maritime quality of high moisture content in at least its lower levels.

MEAN SEA LEVEL—The average height of the sea surface, based upon hourly observation of tide height on the open coast or in adjacent waters that have free access to the sea. In the United States, *mean sea level* is defined as the average height of the surface of the sea for all stages of the tide over a 19-year period.

MERIDIONAL FLOW—A type of atmospheric circulation pattern in which the meridional (north and south) component of motion is unusually pronounced. The accompanying zonal component is usually weaker than normal.

MESOCLIMATE—The climate of small areas of Earth's surface that may not be representative of the general climate of the district. The places considered in mesoclimatology include small valleys, "frost hollows," forest clearings, and open spaces in towns, all of which may have extremes of temperature, differing by many degrees from those of adjacent areas. The mesoclimate is intermediate in scale between the macroclimate and microclimate.

MESOPAUSE—The top of the mesosphere. This corresponds to the level of minimum temperature at 70 to 80 km.

MESOSPHERE—The atmospheric shell between about 20 km and about 70 or 80 km, extending from the top of the stratosphere to the upper temperature minimum (the mesopause). It is characterized by a broad temperature maximum at about 50 km except possibly over the winter polar regions.

METEOROLOGY—The study dealing with the phenomena of the atmosphere. This includes not only the physics, chemistry, and dynamics of the atmosphere, but is extended to include many of the direct effects of the atmosphere upon Earth's surface, the oceans, and life in general.

MICROCLIMATE—The fine climate structure of the air space that extends from the very surface of Earth to a height where the effects of the immediate character of the underlying surface no longer can be distinguished from the general local climate (mesoclimate or macroclimate).

MIGRATORY—Moving; commonly applied to pressure systems embedded in the westerlies and, therefore, moving in a general west-to-east direction.

MILLIBAR—(abbreviated mb) A pressure unit of 1,000 dynes per centimeter, convenient for reporting atmospheric pressures.

MIRAGE—A refraction phenomenon wherein an image of some object is made to appear displaced from its true position.

MOIST AIR—In atmospheric thermodynamics, air that is a mixture of dry air and any amount of water vapor. Generally, air with a high relative humidity.

MOIST TONGUE—An extension or protrusion of moist air into a region of lower moisture content. Cloudiness and precipitation are closely related to moist tongues.

MOISTURE—A general term usually referring to the water vapor content of the atmosphere or to the total water substance (gas, liquid, and solid) present in a given volume of air.

MONSOON—A name for seasonal wind. It was first applied to the winds over the Arabian Sea, which blow for 6 months from the northeast and 6 months from the southwest, but it has been extended to similar winds in other parts of the world.

MONSOON CLIMATE—The type of climate that is found in regions subject to monsoons. It is best developed on the fringes of the tropics.

NEPHANALYSIS—The analysis of a synoptic chart in terms of the types and amounts of clouds and precipitation.

NEPHCURVE—In nephanalysis, a line bounding a significant portion of a cloud system—for example, a clear-sky line, a precipitation line, a cloud-type line, or a ceiling-height line.

NEUTRAL EQUILIBRIUM—A property of the steady state of a system which exhibits neither instability nor stability according to the particular criterion under consideration. A disturbance introduced into such an equilibrium will thus be neither amplified nor damped.

NEUTRAL STABILITY—The state of an unsaturated or saturated column of air in the atmosphere when its environmental lapse rate of temperature is equal to the dry-adiabatic lapse rate or the saturation-adiabatic lapse rate, respectively. Under such conditions a parcel of air displaced vertically will experience no buoyant acceleration.

NEUTRAL WAVE—Any wave whose amplitude does not change with time. In most contexts these waves are referred to as stable waves, the term neutral wave being used when it is important to emphasize that the wave is neither damped nor amplified.

NORTHEAST TRADES—The trade winds of the Northern Hemisphere.

OCCLUDED FRONT—(commonly called *occlusion*; also called *frontal occlusion*) A composite of two fronts, formed as a cold front overtakes a warm front or quasi-stationary front. This is a common process in the late stages of wave-cyclone development, but it is not limited to occurrence within a wave cyclone.

OCCLUSION—Same as OCCLUDED FRONT.

OCEAN WEATHER STATION—As defined by the World Meteorological Organization, a specific maritime location occupied by a ship equipped and staffed to observe weather and sea conditions and report the observations by international exchange.

OROGRAPHIC LIFTING—The lifting of an air current caused by its passage up and over mountains.

OVERRUNNING—A condition existing when an air mass is in motion aloft above another air mass of greater density at the surface. This term is usually applied in the case of warm air ascending the surface of a warm or quasi-stationary front.

PARAMETER—(1) In general, any quantity of a problem that is not an independent variable. More specifically, the term is often used to distinguish, from dependent variables, quantities that may be more or less arbitrarily assigned values for purposes of the problem at hand. (2) Commonly and carelessly used by many meteorologists for almost any meteorological quantity or element.

PARTIAL PRESSURE—The pressure of a single component of a gaseous mixture, according to Dalton's Law.

PERTURBATION—Any departure introduced into an assumed steady state of a system. In synoptic meteorology, the term most often refers to any departure from zonal flow within the major zonal currents of the atmosphere. It is especially applied to the wave-like disturbances within the tropical easterlies.

PHOTOSPHERE—The intensely bright portion of the Sun visible to the unaided eye. It is a shell a few hundred miles in thickness marking the boundary between the dense interior gases of the Sun and the more diffuse cooler gases in the outer portions of the Sun.

PLANETARY BOUNDARY LAYER—(also called *friction layer* or *atmospheric boundary layer*) That layer of the atmosphere from Earth's surface to the geostrophic wind level, including therefore, the surface boundary layer and the Eckman layer.

PLANETARY CIRCULATION—The system of large-scale disturbances in the troposphere when viewed on a hemispheric or worldwide scale. Same as GENERAL CIRCULATION.

POLAR AIR—A type of air whose characteristics are developed over high latitudes, especially within the subpolar highs. Continental polar air (cP) has low surface temperature, low moisture content, and, especially in its source regions, great stability in the lower layers. It is shallow in comparison with arctic air.

POLAR EASTERLIES—The rather shallow and diffuse body of easterly winds located poleward of the subpolar low-pressure belt. In the mean in the Northern Hemisphere, these easterlies exist to an appreciable extent only north of the Aleutian low and Icelandic low.

POLAR FRONT—According to the polar-front theory, the semipermanent, semicontinuous front separating air masses of tropical and polar origin. This is the major front in terms of air mass contrast and susceptibility to cyclonic disturbance.

POLAR OUTBREAK—The movement of a cold air mass from its source region; almost invariably applied to a vigorous equatorward thrust of cold polar air, a rapid equatorward movement of the polar front.

POLAR TROUGH—In tropical meteorology, a wave trough in the westerlies having sufficient amplitude to reach the tropics in the upper air. At the surface it is reflected as a trough in the tropical easterlies, but at moderate elevations it is characterized by westerly winds. It moves generally from west to east and is accompanied by considerable cloudiness at all levels. Cumulus congestus and cumulonimbus clouds are usually found in and around the trough lines. The early and late season hurricanes of the western Caribbean frequently form in polar troughs.

POLAR-FRONT THEORY—A theory originated by the Scandinavian school of meteorologists whereby a polar front, separating air masses of polar and tropical origin, gives rise to cyclonic disturbances, which intensify and travel along the front, passing through various phases of a characteristic life history.

POTENTIAL ENERGY—The energy that a body possesses as a consequence of its position in the field of gravity; numerically equal to the work required to bring the body from an arbitrary standard level, usually taken as mean sea level, to its given position.

PRE-FRONTAL SQUALL LINE—A squall line or instability line located in the warm sector of a wave cyclone, about 50 to 300 miles in advance of the cold front, usually oriented roughly parallel to the cold front and moving in about the same manner as the cold front.

PRESSURE CENTER—On a synoptic chart, a point of local minimum or maximum pressure; the center of a low or high. It is also a center of cyclonic or anticyclonic circulation.

PRESSURE GRADIENT—The rate of decrease (gradient) of pressure in space at a fixed time. The term is sometimes loosely used to denote simply the magnitude of the gradient of the pressure field.

PRESSURE GRADIENT FORCE—The force due to differences of pressure within a fluid mass. In meteorological literature the term usually refers only to horizontal pressure force.

PRESSURE PATTERN—The general geometric characteristics of atmospheric pressure distribution as revealed by isobars on a constant-height chart, usually the surface chart.

PRESSURE SYSTEM—An individual cyclonic-scale feature of atmospheric circulation; commonly used to denote either a high or low; less frequently, a ridge or trough.

PRIMARY CIRCULATION—The prevailing fundamental atmospheric circulation on a planetary scale that must exist in response to (a) radiation differences with latitude, (b) the rotation of Earth, and (c) the particular distribution of land and oceans; and which is required from the viewpoint of conservation of energy.

PROMINENCE—A filament-like protuberance from the chromosphere of the Sun.

QUASI-STATIONARY FRONT—(commonly called *stationary front*) A front that is stationary or nearly so. Conventionally, a front that is moving at a speed less than about 5 knots is generally considered to be quasi-stationary. In synoptic chart analysis, a quasi-stationary front is one that has not moved appreciably from its position on the last (previous) synoptic chart (3 or 6 hours before).

RADAR METEOROLOGICAL OBSERVATION—An evaluation of the echoes that appear on the indicator of a weather radar, in terms of the orientation, coverage, intensity, tendency of intensity, height, movement, and unique characteristics of echoes that may be indicative of certain types of severe storms (such as hurricanes, tornadoes, or thunderstorms) and of anomalous propagation.

RADIATION—(1) The process by which electromagnetic radiation is propagated through free space by virtue of joint undulatory variations in the electric and magnetic fields in space. This concept is to be distinguished from convection and conduction. (2) The process by which energy is propagated through any medium by virtue of the wave motion of that medium, as in the propagation of sound waves through the atmosphere, or ocean waves along the water surface.

RADIATION FOG—A major type of fog, produced over a land area when radiational cooling reduces the air temperature to or below its dew point.

RADIATIONAL COOLING—The cooling of Earth's surface and adjacent air, accomplished (mainly at night) whenever Earth's surface suffers a net loss of heat due to terrestrial radiation.

RADIOSONDE—A balloon-borne instrument for the simultaneous measurement and transmission of meteorological data.

RADIOSONDE OBSERVATION—(commonly contracted to *raob*) An evaluation in terms of temperature, relative humidity, and pressure aloft of radio signals received from a balloon-borne radiosonde; the height of each mandatory and significant pressure level of the observation is computed from these data.

RAINBOW—Any one of a family of circular arcs consisting of concentric colored bands, arranged from red on the inside to blue on the outside, which may be seen on a "sheet" of water drops (rain, fog, or spray).

RAWIN—A method of winds-aloft observation; that is, the determination of wind speeds and directions in the atmosphere above the station. It is accomplished by tracking a balloon-borne radar target or radiosonde transmitter with either radar or a radio direction-finder.

RAWINSONDE—A method of upper-air observation consisting of an evaluation of the wind speed and direction, temperature, pressure, and relative humidity aloft by means of a balloon-borne radiosonde tracked by a radar or radio direction-finder. If radar is used for tracking, a radar target is also attached to the balloon. Thus, it is a radiosonde observation combined with a type of rawin observation.

RECURVATURE—With respect to the motion of severe tropical cyclones (hurricanes and typhoons), the change in direction from westward and poleward to eastward and poleward. Such "recurvature" of the path frequently occurs as the storm moves into middle latitudes.

REDUCTION—In general, the transformation of data from a "raw" form to some usable form. In meteorology, this often refers to the conversion of the observed value of an element to the value that it theoretically would have at some selected or standard level, usually mean sea level. The most common reduction in observing is that of station pressure to sea-level pressure.

REFLECTION—The process whereby a surface of discontinuity turns back a portion of the incident radiation into the medium through which the radiation approached.

REFLECTIVITY—A measure of the fraction of radiation reflected by a given surface; defined as the ratio of the radiant energy reflected to the total that is incident upon that surface. The reflectivity of a given surface for a specified broad spectral range, such as the visible spectrum or the solar spectrum, is referred to as albedo.

REFRACTION—The process in which the direction of energy propagation is changed as the result of a change in density within the propagating medium, or as the energy passes through the interface representing a density discontinuity between two media.

RELATIVE VORTICITY—The vorticity as measured in a system of coordinates fixed on Earth's surface. Usually, only the vertical component of the vorticity is meant.

RESOLUTION—The ability of an optical system to render visible separate parts of an object, or to distinguish between different sources of light.

RESULTANT WIND—In climatology, the vectorial average of all wind directions and speeds for a given level at a given place for a certain period, as a month. It is obtained by resolving each wind observation into components from north and east, summing over the given period, obtaining the averages, and reconverting the average components into a single vector.

RETROGRADE—The motion of an atmospheric wave or pressure system in a direction opposite to that of the basic flow in which it is embedded.

RIDGE—An elongated area of relatively high atmospheric pressure. The most common use of this term is to distinguish it from the closed circulation of a high; but a ridge may include a high, and a high may have one or more distinct ridges radiating from its center.

SCATTERING—The process by which small particles suspended in a medium of a different index of refraction diffuse a portion of the incident radiation in all directions.

SEA BREEZE—A coastal local wind that blows from sea to land, caused by the temperature difference when the sea surface is colder than the adjacent land. Therefore, it usually blows on relatively calm, sunny, summer days; and alternates with the oppositely directed, usually weaker, nighttime land breeze.

SEA LEVEL—The height or level of the sea surface.

SEA-BREEZE FRONT—A sea breeze that forms out over the water, moves slowly toward the coast and then moves inland quite suddenly. Often associated with the passage of this type of sea breeze are showers, a sharp wind shift from seaward to landward, and a sudden drop in temperature. The leading edge of such a sea breeze is sometimes called the sea-breeze front.

SEASON—A division of the year according to some regularly recurrent phenomena, usually astronomical or climatic. Astronomical seasons extend from an equinox to the next solstice or vice versa. Climatic seasons are often based on precipitation (rainy and dry seasons).

SECONDARY CIRCULATION—Atmospheric circulation features of synoptic scale.

SECONDARY FRONT—A front that forms within a baroclinic cold-air mass that itself is separated from a warm-air mass by a primary frontal system. The most common type is the secondary cold front.

SEMIDIURNAL TIDE—A tidal cycle that generally has two high tides and two low tides each day.

SHEAR—The variation (usually the directional derivative) of a vector field along a given direction in space. The most frequent context for this concept is wind shear.

SHEAR LINE—A line or narrow zone across which there is an abrupt change in the horizontal wind component parallel to this line; a line of maximum horizontal wind shear.

SHORT WAVE—With regard to atmospheric circulation, a progressive wave in the horizontal pattern of air motion with dimensions of synoptic scale, as distinguished from a long wave.

SHORT-WAVE RADIATION—A term used loosely to distinguish radiation in the visible and near-visible portions of the electromagnetic spectrum (roughly 0.4 to 1.0 micron in wavelength) from long-wave radiation.

SIBERIAN HIGH—A cold-core high-pressure area that forms over Siberia in winter, and which is particularly apparent on mean charts of sea-level pressure.

SINGULAR POINT—In a flow field, a point at which the direction of flow is not uniquely determined, hence a point of zero speed, e.g., a col.

SMOOTHING—An averaging of data in space or time, designed to compensate for random errors or fluctuations of a scale smaller than that presumed significant to the problem at hand; the analysis of a sea-level weather map smoothes the pressure field on a space-scale more or less systematically determined by the analyst by taking each pressure as representative not of a point but of an area about the point.

SOLAR CONSTANT—The rate at which solar radiation is received outside Earth's atmosphere on a surface normal to the incident radiation, and at Earth's mean distance from the Sun.

SOLSTICE—(1) Either of two points on the Sun's apparent annual path where it is displaced farthest north or south from Earth's equator. The Tropic of Cancer (north) and Tropic of Capricorn (south) are defined as the parallels of latitude that lie directly beneath a solstice. (2) Popularly, the time at which the Sun is farthest north or south; the "time of the solstice." In the Northern Hemisphere, the summer solstice falls on or about 21 June, and the winter solstice on or about 22 December. The reverse is true in the southern latitudes.

SOUNDING—In meteorology, the same as upper-air observation.

SPECIFIC HEAT—The heat capacity of a system per unit mass. That is, the ratio of the heat absorbed (or released) by unit mass of the system to the corresponding temperature rise (or fall).

SPECIFIC HUMIDITY—In moist air, the ratio of the mass of water vapor to the total mass of the system. For many purposes it may be approximated by the mixing ratio.

SPECULAR REFLECTION—Reflection in which the reflected radiation is not diffused; reflection as from a mirror.

SPIRAL BAND—Spiral-shaped radar echoes received from precipitation areas within intense tropical cyclones. They curve cyclonically in toward the center of the storm and appear to merge to form the wall around the eye of the storm.

SQUALL LINE—Any non-frontal line or narrow band of active thunderstorms.

STANDARD ATMOSPHERE—A hypothetical vertical distribution of atmospheric temperature, pressure, and density that by international agreement is taken to be representative of the atmosphere for purposes of pressure altimeter calibrations, aircraft-performance calculations, aircraft and missile design, ballistic tables, etc. The air is assumed to obey the perfect gas law and the hydrostatic equation, which, taken together, relate temperature, pressure, and density variations in the vertical. It is further assumed that the air contains no water vapor and that the acceleration of gravity does not change with height.

STEERING CURRENT—A basic fluid flow that exerts a strong influence upon the direction of movement of disturbances embedded in it.

STEERING LEVEL—A level, in the atmosphere, where the velocity of the basic flow bears a direct relationship to the velocity of movement of an atmospheric disturbance embedded in the flow.

STORM—Any disturbed state of the atmosphere, especially as affecting Earth's surface, and strongly implying destructive or otherwise unpleasant weather. Storms range in scale from tornadoes and thunderstorms, through tropical cyclones, to widespread extratropical cyclones.

STORM SURGE—(also called *storm tide*) An abnormal rise of the sea along a shore as the result, primarily, of storm winds.

STRATOSPHERE—The atmospheric shell above the troposphere and below the mesosphere. It extends, therefore, from the tropopause to the height where the temperature begins to increase in the 20- to 25-km region.

STREAMLINE—A line whose tangent at any point in a fluid is parallel to the instantaneous velocity of the fluid at that point.

SUBGRADIENT WIND—A wind of lower speed than the gradient wind required by the existing pressure gradient and centrifugal force.

SUBLIMATION—The transition of a substance from the solid phase directly to the vapor phase, or vice versa, without passing through an intermediate liquid phase.

SUBSIDENCE—A descending motion of air in the atmosphere, usually with the implication that the condition extends over a rather broad area.

SUBSIDENCE INVERSION—A temperature inversion produced by the adiabatic warming of a layer of subsiding air. This inversion is enhanced by vertical mixing of the air layer below the inversion.

SUBTROPICAL HIGH—One of the semi-permanent highs of the subtropical high-pressure belt. They appear as centers of action on mean charts of surface pressure. They lie over oceans and are best developed in summer.

SUBTROPICAL HIGH-PRESSURE BELT—One of the two belts of high atmospheric pressure that are centered, in the mean, near 30°N and 30°S latitudes.

SUNSPOT—A relatively dark area on the surface of the Sun, consisting of a dark central umbra surrounded by a penumbra, which is intermediate in brightness between the umbra and the surrounding photosphere.

SUPERADIABATIC LAPSE RATE—An environmental lapse rate greater than the dry-adiabatic lapse rate, such that potential temperature decreases with height.

SUPERCOOLING—The reduction of temperature of any liquid below the melting point of that substance's solid phase; that is, cooling beyond its nominal freezing point.

SUPERGRADIENT WIND—A wind of greater speed than the gradient wind required by the existing pressure gradient and centrifugal force.

SUPERIOR AIR—An exceptionally dry mass of air formed by subsidence and usually found aloft but occasionally reaching Earth's surface during extreme subsidence processes.

SUPERIOR MIRAGE—A spurious image of an object formed above its true position by abnormal refractive conditions; opposite of *inferior mirage.*

SUPERSATURATION—The condition existing in a given portion of the atmosphere (or other space) when the relative humidity is greater than 100 percent; that is, when it contains more water vapor than is needed to produce saturation with respect to a plane surface of pure water or pure ice.

SURFACE BOUNDARY LAYER—That thin layer of air adjacent to Earth's surface in which the air movement is affected by friction caused by the Earth's surface.

SURFACE CHART—(also called *surface map, sea-level chart, sea-level pressure chart*) An analyzed synoptic chart of surface weather observations. It shows the distribution of sea-level pressure (positions of highs, lows, ridges, and troughs) and the location and nature of fronts and air masses. Often added to this are symbols of occurring weather phenomena, analysis of pressure tendency (isallobars), indications of the movement of pressure systems and fronts, and perhaps others, depending on the use of the chart.

SURFACE INVERSION—A temperature inversion based at Earth's surface; that is, an increase of temperature with height beginning at ground level.

SURFACE OF DISCONTINUITY—A surface separating two fluids across which there is a discontinuity of some fluid property, such as density, velocity, etc., or of some derivative of one of these properties in a direction normal to the interface. An atmospheric front is represented ideally by a surface of discontinuity of velocity, density, temperature, and pressure gradient; the tropopause is represented ideally by a surface of discontinuity of, for example, the derivatives: lapse rate and wind shear.

SYNOPTIC—In general, pertaining to or affording an overall view. In meteorology, this term has become somewhat specialized in referring to the use of meteorological data obtained simultaneously over a wide area for the purpose of presenting a comprehensive and nearly instantaneous picture of the state of the atmosphere.

SYNOPTIC CHART—In meteorology, any chart or map on which data and analyses are presented that describe the state of the atmosphere over a large area at a given moment in time.

SYNOPTIC SCALE—The scale of the migratory high- and low-pressure systems (or cyclonic waves) of the lower troposphere, with wavelengths of 1,000 to 2,500 km.

SYNOPTIC SITUATION—The general state of the atmosphere as described by the major features of synoptic charts.

TEMPERATURE INVERSION—A layer in which temperature increases with altitude.

TERTIARY CIRCULATION—The generally small, localized atmospheric circulations. They are represented by such phenomena as the local winds, thunderstorms, and tornadoes.

THERMAL—(1) Pertaining to temperature or heat. (2) A relatively-small-scale rising current of air produced when the atmosphere is heated enough locally by Earth's surface to produce absolute instability in its lower layers. The use of this term is usually reserved to denote those currents either too small and/or too dry to produce convective clouds; thus, thermals are a common source of low-level clear-air turbulence.

THERMAL GRADIENT—The rate of variation of temperature either horizontally or vertically.

THERMAL HIGH—An area of high pressure resulting from the cooling of air by a cold underlying surface, and remaining relatively stationary over the cold surface.

THERMAL LOW—An area of low atmospheric pressure resulting from high temperatures caused by intense surface heating. Thermal lows are stationary with a generally weak and diffuse cyclonic circulation. They are nonfrontal.

THERMAL WIND—The mean wind-shear vector in geostrophic balance with the mean temperature gradient of a layer bounded by two isobaric surfaces.

THERMOSPHERE—The atmospheric shell extending from the top of the mesosphere to outer space. It is a region of more or less steadily increasing temperature with height, starting at 70 or 80 km.

THICKNESS—In synoptic meteorology, the vertical depth, measured in geometric or geopotential units, of a layer in the atmosphere bounded by surfaces of two different values of the same physical quantity, usually constant-pressure surfaces.

THICKNESS CHART—A type of synoptic chart showing the thickness of a certain physically defined layer in the atmosphere. It almost always refers to an isobaric thickness chart, that is, a chart of vertical distance between two constant-pressure surfaces. It consists of a pattern of thickness lines either drawn directly to data plotted on the chart or, more commonly, drawn by the single graphical process of differential analysis.

THICKNESS LINE—A line drawn through all geographic points at which the thickness of a given atmospheric layer is the same; an isopleth of thickness.

TORNADO—A violently rotating column of air, pendant from a cumulonimbus cloud, and nearly always observable as a "funnel cloud" or tuba.

TRADE WINDS—The wind system, occupying most of the tropics, that blows from the subtropical highs toward the equatorial trough.

TRADE-WIND CUMULUS—The characteristic cumulus cloud in average, undisturbed, weather conditions over the trade-wind belts.

TRADE-WIND INVERSION—A characteristic temperature inversion usually present in the trade-wind streams over the eastern portions of the tropical oceans.

TRIPLE POINT—Term commonly used to denote the apex of an occlusion.

TROPICAL AIR—A type of air whose characteristics are developed over low latitudes. Maritime tropical air (mT) is produced over the tropical and subtropical seas, while continental tropical air is produced over subtropical arid regions.

TROPICAL CYCLONE—The general term for a cyclone that originates over the tropical oceans. By international agreement, tropical cyclones are classified according to their intensity (the strength of their surface winds).

TROPICAL DEPRESSION—A tropical cyclone having a slight surface circulation (at least one closed isobar) and surface winds less than 34 knots.

TROPICAL DISTURBANCE—An area of disturbed weather over the tropical oceans that often develops into a tropical cyclone.

TROPICAL EASTERLIES—A term applied to the trade winds when they are shallow and exhibit a strong vertical shear. With this structure, at about 5,000 feet the easterlies give way to the upper westerlies, which are sufficiently strong and deep to govern the course of cloudiness and weather. They occupy the poleward margin of the tropics in summer and can cover most of the tropical belt in winter.

TROPICAL STORM—A tropical cyclone whose surface winds have attained speeds between 34 and 63 knots.

TROPICS—Classically, the region of Earth between the Tropic of Cancer (23 1/2°N) and the Tropic of Capricorn (23 1/2°S). In modern meteorology, this term refers to the region of Earth between 30°N and 30°S latitudes.

TROPOPAUSE—The boundary between the troposphere and stratosphere, usually characterized by an abrupt change of lapse rate.

TROPOSPHERE—That portion of Earth's atmosphere extending from the surface to the tropopause; that is, the lowest 10 to 20 km of the atmosphere.

TROUGH—An elongated area of low atmospheric pressure; the opposite of a ridge.

TRUE NORTH—The direction from any point on Earth's surface toward the geographic North Pole; the northerly direction along any projection of Earth's axis upon Earth's surface, for example, along a longitude line. Except for much of navigational practice (which uses magnetic north), true north is the universal 0° (or 360°) mapping reference.

UPPER AIR—In synoptic meteorology and weather observing, that portion of the atmosphere that is above the lower troposphere. No distinct lower limit is set, but the term is generally applied to the levels above 850 mb.

UPPER ATMOSPHERE—The general term applied to the atmosphere above the troposphere.

UPPER FRONT—A front that is present in the upper air but does not extend to the ground.

UPPER-LEVEL HIGH—(also called *upper-level anticyclone*, *upper high*, *high aloft*) An anticyclonic circulation existing in the upper air. Upper-level high often refers to such highs only when they are much more pronounced at upper levels than at the surface.

UPPER-LEVEL LOW—(also called *upper-level cyclone*, *upper cyclone*, *high-level cyclone*, *low aloft*) A cyclonic circulation existing in the upper air, specifically as seen on an upper-level constant-pressure chart. This term is often restricted to such lows having little cyclonic circulation in the lower atmosphere.

UPPER-LEVEL RIDGE—A pressure ridge existing in the upper air, especially one that is stronger aloft than near Earth's surface.

UPPER-LEVEL TROUGH—A pressure trough existing in the upper air. This term is sometimes restricted to those troughs that are much more pronounced aloft than near Earth's surface.

UPSTREAM—In the direction from which a fluid is flowing.

UPWIND—In the direction from which the wind is blowing.

UTC—Universal Time Coordinated. Formerly called Greenwich Mean Time, or GMT.

VECTOR—Any quantity, such as force, velocity, or acceleration, that has both magnitude and direction at each point in space, as opposed to a scaler, which has magnitude only. Geometrically, it is represented by an arrow of length proportional to its magnitude, pointing in the assigned direction.

VEERING—A change in wind direction in a clockwise sense in the Northern Hemisphere and counterclockwise direction in the Southern Hemisphere.

VERNAL EQUINOX—For either hemisphere, the equinox at which the Sun's most direct rays approach from the opposite hemisphere. In northern latitudes, this occurs approximately on 21 March; the Sun's most direct rays are centered over the equator and moving north.

VIRTUAL TEMPERATURE—In a system of moist air, the temperature of dry air having the same density and pressure as the moist air. It is always greater than the actual temperature.

VORTEX—In its most general use, any flow possessing vorticity. More often the term refers to a flow with closed streamlines.

VORTICITY—A vector measure of local rotation in a fluid flow.

WARM FRONT—Any non-occluded front or portion thereof that moves in such a way that warmer air replaces colder air.

WARM SECTOR—That area within the circulation of a wave cyclone where the warm air is found. It lies between the cold front and the warm front of the storm; and, in the typical case, the warm sector continually diminishes in size and ultimately disappears (at the surface) as the result of occlusion.

WARM TONGUE—A pronounced poleward extension or protrusion of warm air.

WARM-CORE HIGH—At a given level in the atmosphere, any high that is warmer at its center than at its periphery.

WARM-CORE LOW—At a given level in the atmosphere, any low that is warmer at its center than at its periphery.

WAVE CYCLONE—A cyclone that forms and moves along a front.

WAVE THEORY OF CYCLONES—A theory of cyclone development based upon the principles of wave formation on an interface between two fluids. In the atmosphere, a front is taken as such an interface.

WEATHER—The state of the atmosphere, mainly with respect to its effect upon life and human activities.

WEATHER RADAR—Generally, any radar that is suitable or can be used for the detection of precipitation or clouds.

WESTERLIES—(also known as *circumpolar westerlies*, *countertrades*, *middle-latitude westerlies*, *midlatitude westerlies*, *polar westerlies*, *subpolar westerlies*, *subtropical westerlies*, *temperate westerlies*, *zonal westerlies*, and *zonal winds*) Specifically, the dominant west-to-east motion of the atmosphere, centered over the middle latitudes of both hemispheres. At the surface, the westerly belt extends, on the average, from about 35° to 65° latitude. At upper levels, the westerlies extend farther equatorward and poleward. The equatorward boundary is fairly well defined by the subtropical high-pressure belt; the poleward boundary is quite diffuse and variable.

WHITEOUT—An atmospheric optical phenomenon of the polar regions in which the observer appears to be engulfed in a uniformly white glow. Shadows, horizon, and clouds are not discernible; sense of depth and orientation are lost; only very dark, nearby objects can be seen.

WIND ROSE—Any one of a class of diagrams designed to show the distribution of wind direction experienced at a given location over a considerable period; it thus shows the prevailing wind direction. The most common form consists of a circle from which 8 or 16 lines emanate, one for each compass point. The length of each line is proportional to the frequency of wind from that direction, and the frequency of calm conditions is entered in the center.

WIND-CHILL FACTOR—The cooling effect of any combination of temperature and wind, expressed as the loss of body heat, in kilogram calories per hour per square meter of skin surface. The wind-chill factor is based on the cooling rate of a nude body in the shade; it is only an approximation, because of individual body variations in shape, size, and metabolic rate.

WINTER SOLSTICE—For either hemisphere, the solstice at which the Sun is above the opposite hemisphere. In northern latitudes, the time of this occurrence is approximately 22 December.

ZONAL—Latitudinal; easterly or westerly; opposed to meridional.

ZONAL FLOW—The flow of air along a latitude circle; more specifically, the latitudinal (east or west) component of existing flow.

ZONAL INDEX—A measure of strength of the midlatitude westerlies, expressed as the horizontal pressure difference between 35° and 55° latitude or as the corresponding geostrophic wind.

APPENDIX II

FLIGHT WEATHER BRIEFING FORM (DD FORM 175-1)

The following are the general rules to use when filling in the DD Form 175-1:

1. Times and dates are entered using Greenwich Mean Time (GMT).
2. Heights are entered to the nearest hundred feet above MSL using three digits (e.g., 800 feet = 008, 1,200 feet = 012, and 15,000 feet = 150).
3. All wind directions are entered in tens of degrees true, and wind speeds in knots. Wind speed and direction groups consist of four digits.
4. Use of the word *enroute* is NOT authorized.
5. Unless otherwise specified by the pilot, terminal forecasts are entered in the Airways Code format.

PART I—MISSION/TAKEOFF DATA

Part I identifies the date of the briefing, the aircraft type and number, point of departure, and the estimated time of departure (ETD). It also lists the forecast conditions for takeoff and climb to flight level.

<table>
<tr><th colspan="8">FLIGHT WEATHER BRIEFING</th></tr>
<tr><th colspan="8">PART I - MISSION / TAKEOFF DATA</th></tr>
<tr><td>DATE</td><td>ACFT TYPE / NO</td><td>DEP PT / ETD
Z</td><td>RUNWAY TEMP
°F/C</td><td>DEWPOINT
°F/C</td><td>TEMP DEV
°C</td><td>PRESSURE ALT
FT</td><td>DENSITY ALT
FT</td></tr>
<tr><td>SFC WIND M
T</td><td colspan="2">CLIMB WINDS</td><td colspan="3">LOCAL WEA WRNG / MET WATCH ADV</td><td colspan="2">RCR</td></tr>
<tr><td colspan="8">REMARKS / TAKEOFF ALTN FCST</td></tr>
</table>

DATE—Enter the day, month, and year (e.g., 21 October 1989 is entered 21OCT89).

ACFT TYPE/NO.—Enter the type of aircraft, and the bureau number (BUNO), call sign, or event number as appropriate (e.g. A4/163082; F14/BUC44; or P3/OL177). If more than one aircraft is involved, the data is entered above the block or in one of the remarks sections.

DEP PT/ETD—Enter station identifier and the estimated time of departure (e.g., NPA/1430 or MUGM/0015).

RUNWAY TEMP—Enter the forecast ambient air temperature in degrees Fahrenheit and/or degrees Celsius, as requested by the pilot.

DEWPOINT—Enter the forecast dewpoint in degrees Fahrenheit and/or degrees Celsius, as requested by the pilot.

TEMP DEV—Enter the algebraic difference between the forecast runway temperature and the U.S. Standard Atmosphere temperature corresponding to field elevation. Enter in degrees Fahrenheit and/or degrees Celsius as appropriate using the appropriate sign.

PRESSURE ALT—Enter in feet, using appropriate sign.

DENSITY ALT—Enter in feet, using appropriate sign.

SFC WIND (M) (T)—Enter the forecast surface wind for the ETD. Note whether the wind is "magnetic" or "true".

CLIMB WINDS—Enter the forecast winds on climb to flight level. The winds may be listed by increments, or you may simply use a mean value.

LOCAL WEA WRNG/MET WATCH ADV—Enter any local weather warnings or advisories that could affect the aircraft during takeoff and climb-out. If no warnings or advisories are in effect, enter "NONE".

RCR—Enter the equivalent braking action as reported by base air operations, if appropriate. For example, the entry IR10 means ice on runway, decelerometer reading 10.

REMARKS/TAKEOFF ALTN FCST—Enter any significant or unusual takeoff and climb conditions not previously indicated. Enter the weather forecast for the takeoff alternate airfield when the alternate is required or requested; use the TAF Code.

PART II—ENROUTE DATA

Part II applies to the weather conditions at least 25 nautical miles either side of the flight path and 5,000 feet above or below cruise altitude between the point of departure and the point of termination. Any warnings (WWs/SIGMETS/AIRMETS) in effect along the proposed route of flight are also entered in Part IV and are orally briefed.

PART II - ENROUTE DATA

FLT LEVEL	FLT LEVEL WINDS / TEMP

CLOUDS AT FLT LEVEL	MINIMUM VISIBILITY AT FLT LEVEL OUTSIDE CLOUDS MILES DUE TO	
☐ YES ☐ NO ☐ IN AND OUT	☐ SMOKE ☐ DUST ☐ HAZE ☐ FOG ☐ PRECIPITATION ☐ NO OBSTRUCTION	
MINIMUM CEILING LOCATION FT AGL	MAXIMUM CLOUDS TOPS LOCATION FT MSL	MINIMUM FREEZING LEVEL LOCATION FT MSL

THUNDERSTORMS	TURBULENCE			ICING				PRECIPITATION				
MWA/WW NO	CAT ADVISORY Z			NONE				NONE				
☐ NONE ☐ AREA ☐ LINE	☐ NONE	IN CLEAR	IN CLOUD		RIME	MIXED	CLEAR		DRIZ	RAIN	SNOW	SLEET
☐ ISOLATED 1 - 2%	LIGHT			TRACE				LT				
☐ FEW 3 15%	MOD			LIGHT				MOD				
☐ SCATTERED 16 - 45%	SVR			MOD				HVY				
☐ NUMEROUS MORE THAN 45%	EXTREME			SVR				SHWRS				
HAIL, SVR, TURB, SEVERE, ICING, PRECIPITATION AND LIGHTNING EXPECTED IN AND NEAR TSTMS	LEVELS			LEVELS				FRZG				
LOCATION	LOCATION			LOCATION				LOCATION				

FLT LEVEL—Enter the flight level(s) (e.g., 250 to NBE).

FLT LEVEL WINDS/TEMP—Enter as many increments of winds and temperatures (in degrees Celsius) as are necessary to accurately describe the enroute wind and temperature conditions. The use of "See wind charts" or "See OPARS # " is not authorized unless (1) a flight forecast folder is being provided or (2) OPARS data is being used. A copy of the OPARS printout must be attached to the in-house copy of the DD Form 175-1.

CLOUDS AT FLT LEVEL—Check the block that best describes the forecast cloud conditions at flight level. The "YES" block signifies more than 45% of the flight is in clouds. The "NO" block signifies less than 1% of the flight is in clouds. "IN AND OUT" signifies that between 1% and 45% of the flight is through clouds.

MINIMUM VISIBILITY AT FLT LEVEL OUTSIDE OF CLOUDS MILES DUE TO—Enter the forecast minimum horizontal visibility at flight level outside of clouds, in statute miles. When precipitation or obstructions to vision are forecast, check the appropriate block(s). If no restricting phenomena are forecast, the "NO OBSTRUCTION" block is checked. Variable-range entries (e.g., 1V3) are NOT authorized.

MINIMUM CEILING (LOCATION)—Enter the height of the forecast minimum ceiling in hundreds of feet above ground level (AGL) and the ceiling's location along the flight route.

MAXIMUM CLOUD TOPS (LOCATION)—Enter the forecast maximum tops of significant clouds (excluding thunderstorms) along the route, and indicate their location(s). Entries are relative to the aircraft's flight level (e.g., if the flight level is 16,000 feet, then the tops of middle or low clouds should be entered rather than the top of a cirrus layer). However, there is one exception: Aircraft involved in celestial navigation flights are provided maximum cloud tops above their proposed flight level.

MINIMUM FREEZING LEVEL (LOCATION)—Enter the height of the minimum freezing in hundreds of feet above MSL and its location along the route of flight.

THUNDERSTORMS—Pilots must be made aware of all thunderstorm activity along the flight route, regardless of the aircraft's proposed flight level.

MWA/WW NO.:—Enter any WW/SIGMET/MWA number when appropriate. If none, leave this block blank.

NONE—Check this block when no thunderstorm activity is forecast.

AREA—Check this block to signify that the thunderstorm activity will be the air mass variety or in clusters.

LINE—Check this block when the forecasted thunderstorms will be in a line(s). Frontal, squall line, and topographically induced convective activity are prime examples of this type of thunderstorm activity.

NOTE

Whenever thunderstorms are forecast, either the AREA block or the LINE block must be checked.

Area-of-coverage blocks range from ISOLATED 1 - 2% to NUMEROUS - more than 45%. The forecaster must determine if one value for the area of coverage will suffice. If only one value is checked and briefed, then nowhere along the route of flight should that value be exceeded. So if need be, more than one value should be checked and briefed. For every area of coverage checked, the tops of the thunderstorm activity within the area is entered to the right of the percentage value, in hundreds of feet.

When more than one block is checked, the different areas of coverage must be matched up with their expected locations. Since there is only one LOCATION block, I recommend assigning letters to each area of coverage checked. For example, if the ISOLATED and FEW blocks have been checked, place the letter a to the left of ISOLATED and the letter b to the left of FEW. Then, in the LOCATION block, use the letters to distinguish each area of coverage.

LOCATION—Enter the location of the forecast thunderstorm activity using standard geographical locations or LAT/LONG as appropriate.

TURBULENCE—Inform pilots/aircrews of expected turbulence not associated with thunderstorms.

CAT ADVISORY—Enter the date/time group of any SIGMET/FAXN, OR AIRMET. If the forecasted turbulence is based on a SIGMET or AIRMET, strike out CAT and substitute the appropriate entry.

NONE—Check this block when no turbulence is forecast.

IN CLEAR—Check this block when the turbulence is forecast to occur outside of clouds.

IN CLOUD—Check this block when the turbulence is forecast to occur in clouds.

Intensity blocks range from LIGHT to EXTREME. The forecaster must decide which block(s) to check. The National Aeronautics and Space Administration (NASA) developed the following criteria so that pilots could more accurately report turbulence encountered during flights.

Adjective Class	Transport Aircraft Operational Criteria	Derived Gust Velocity Criteria
Light	A turbulent condition during which occupants may be required to use seat belts, but objects in the aircraft remain at rest.	5 to 20 feet per second.
Moderate.....	A turbulent condition in which occupants require seat belts and occasionally are thrown against the belt. Unsecured objects in the aircraft move about.	20 to 35 feet per second.
Severe	A turbulent condition in which the aircraft momentarily may be out of control. Occupants are thrown violently against the belt and back into the seat. Objects not secured in the aircraft are tossed about.	35 to 50 feet per second.
Extreme......	A rarely encountered turbulent condition in which the aircraft is violently tossed about, and is practically impossible to control. May cause structural damage.	More than 50 feet per second.

LEVELS—Ensure that the upper and lower limits of the turbulence zone are shown in this block. For example, if light turbulence is forecast in clouds between 8,000 and 11,000 feet, enter 080 - 110.

LOCATION—The location(s) of the forecast turbulence is entered in this block using geographical locations and LAT/LONG as appropriate.

ICING—Inform pilots/aircrews of expected icing NOT associated with thunderstorms.

NONE—If no icing is forecast, check this block.

RIME/MIXED/CLEAR—The type(s) of icing forecast and the expected severity (TRACE, LIGHT, MOD, or SVR) are checked.

LEVELS—Enter the upper and lower limits of the forecasted icing in hundreds of feet above MSL.

LOCATION—Entries are made using geographical locations or LAT/LONG as appropriate.

PRECIPITATION—The type, intensity, and location of all forecasted precipitation along the flight route are given in the following blocks.

DRIZ/RAIN/SNOW/SLEET—Check the type(s) of precipitation forecasted and the expected intensity level(s) (LT, MOD, HVY) or form(s) (SHWRS, FRZG) of precipitation.

LOCATION—Enter geographical locations or LAT/LONG as appropriate.

PART III—TERMINAL FORECAST

Enter the forecast conditions at the final destination, at any intermediate stops, and at all required alternates under the column titled AIRDROME. If additional space is required, use another DD Form 175-1.

PART III - TERMINAL FORECASTS

AIRDROME	CLOUD LAYERS	VSBY/WEA	SFC WIND	ALTIMETER	VALID TIME
DEST/ALTN				INS	Z TO Z
DEST/ALTN				INS	Z TO Z
DEST/ALTN				INS	Z TO Z
DEST/ALTN				INS	Z TO Z
DEST/ALTN				INS	Z TO Z
DEST/ALTN				INS	Z TO Z
DEST/ALTN				INS	Z TO Z
DEST/ALTN				INS	Z TO Z

AIRDROME (DEST/ALTN)—Enter the station identifier of each destination and alternate airfield. Cross out the non-applicable designator (DEST/ALTN). If more than one stop is planned, entries are made in chronological order of flight.

CLOUD LAYERS, VSBY/WEA, SFC WIND—Opposite each destination and alternate airfield, enter the forecast conditions expected 1 hour before and 1 hour after the aircraft's scheduled arrival time (valid time). Any changes to the forecast conditions during the valid time are entered on the next line and preceded by the expected type of change (e.g., TEMP, OCNL).

ALTIMETER—Enter the minimum altimeter setting for the valid time of the forecast.

VALID TIME—The valid time covers the period 1 hour before to 1 hour after the ETA at the indicated airdrome.

PART IV—COMMENTS/REMARKS

PART IV - COMMENTS / REMARKS		
BRIEFED ON LATEST RCR FOR DESTN AND ALTN	☐ YES ☐ NOT AVAILABLE	REQUEST PIREP AT

Check the YES or NOT AVAILABLE block concerning runway conditions, and list specific locations where PIREPS will be beneficial.

Unless otherwise requested, the last hourly observation from the first scheduled arrival point is entered in this space. Be sure to include the station identifier and the time of the observation. Use the remainder of this section to describe any significant data that is not covered elsewhere on the form and that you deem pertinent.

PART V—BRIEFING RECORD

Part V is used to record the time the briefing was completed, the briefing number, the forecaster's signature, and the void time of the briefing. It also includes blocks for an extension time (a new void time), the time of any rebriefing, and the initials of the forecaster granting the extension or rebriefing and those of the person receiving the extension or rebriefing.

PART V - BRIEFING RECORD				
WEA BRIEFED Z		FLIMSY BRIEFING NO	FORECASTER'S SIGNATURE OR INITIALS	
VOID TIME Z	EXTENDED TO Z	WEA REBRIEFED AT Z	FORECASTER'S INIT	NAME OF PERSON RECEIVING BRIEFING

DD Form 175-1, FEB 87 *Previous edition may be used*

WEA BRIEFED—Enter the time the briefing was issued.

FLIMSY BRIEFING NO.:—Enter the briefing number using the month (two digits) and a sequential briefing number (three digits). For example, if you are conducting the 21st briefing during the month of October, the entry is 10/021.

FORECASTER'S SIGNATURE OR INITIALS—The forecaster must sign or initial this block. The entry must be LEGIBLE.

VOID TIME—The void time is obtained by adding one-half hour to the aircraft's ETD. The void time is the time a briefing becomes invalid. The void time must never exceed the briefing time (WEA BRIEFED or WEA REBRIEFED AT blocks) by more than 2 1/2 hours. Whenever a briefing is updated beyond this 2 1/2-hour limit, a new void time is entered based on the aircraft's revised ETD.

EXTENDED TO—This block is for extensions to the void time. When a request for an extension is received, the forecaster reviews the DD Form 175-1 to ensure that the briefing is still valid. If there are no changes to the information on the DD Form 175-1, the new void time is entered in this block.

WEA REBRIEFED AT—Whenever DD Form 175-1 is updated in any manner by the forecaster, including an extension request, enter the time the rebriefing is completed. If the changes to the form are considered too excessive or too critical, a new briefing (DD Form 175-1) should be issued.

FORECASTER'S INIT—The initials of the forecaster granting the extension, as well as those of the individual receiving the rebriefing are entered in this block.

NAME OF PERSON RECEIVING BRIEFING—Enter the rank/rate and last name of person receiving the briefing.

APPENDIX III

THE DUCTOGRAM AND INSTRUCTIONS FOR ITS USE

The following steps are applied when using the ductogram:

1. Refer to the ductogram, in figure AIII-1, and find the intersection of the air temperature and dew point in the lower right section.

2. Extend the line horizontally across to the left section of the diagram to the sea surface temperature (T_S).

3. Read ΔN (the difference between N at the observation level and N at the sea surface). In order for trapping to be present, N must be a negative value; and the greater the absolute value of N, the greater the intensity of trapping.

4. Refer to the appropriate diagram (for specific radar frequency) to determine the intensity of trapping. See figures AIII-2A, AIII-2B, and AIII-2C.

a. First, obtain the current wind speed, and the difference between the air temperature and sea-surface temperature ($T_A - T_S$). This is ΔT. The ΔT values are represented by skewed lines on these graphs.

b. Based on the type of radar(s) to be used, use the appropriate diagram(s). Follow the vertical line for the current wind speed upward to the curved line for the value of ΔT.

c. From the intersection of ΔT and the wind speed line, move left horizontally and read the N value. This value will determine whether or not trapping conditions are present.

5. Fill in the ductogram worksheet (fig. AIII-3).

DUCTOGRAM
(USING SHIP REPORTS)

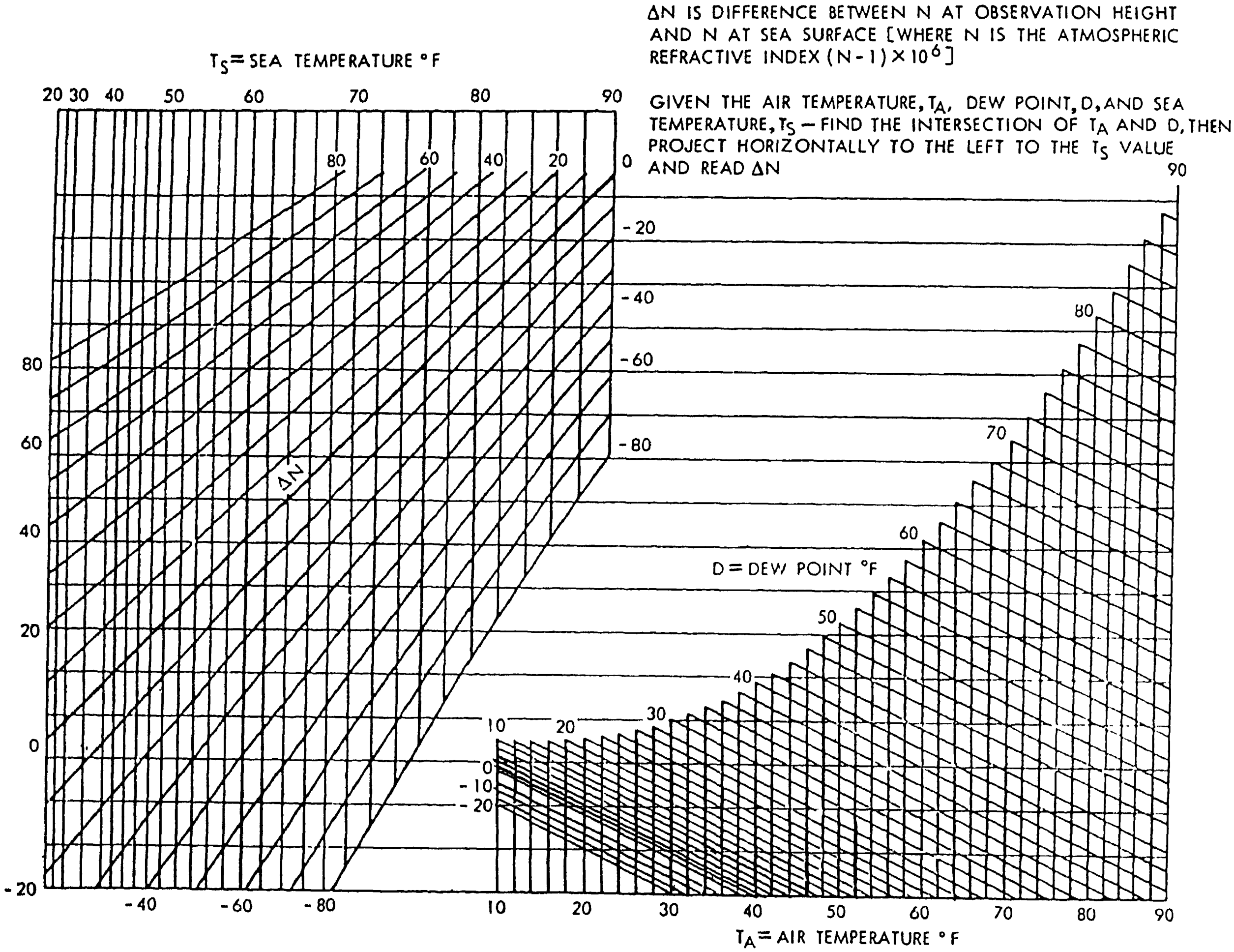
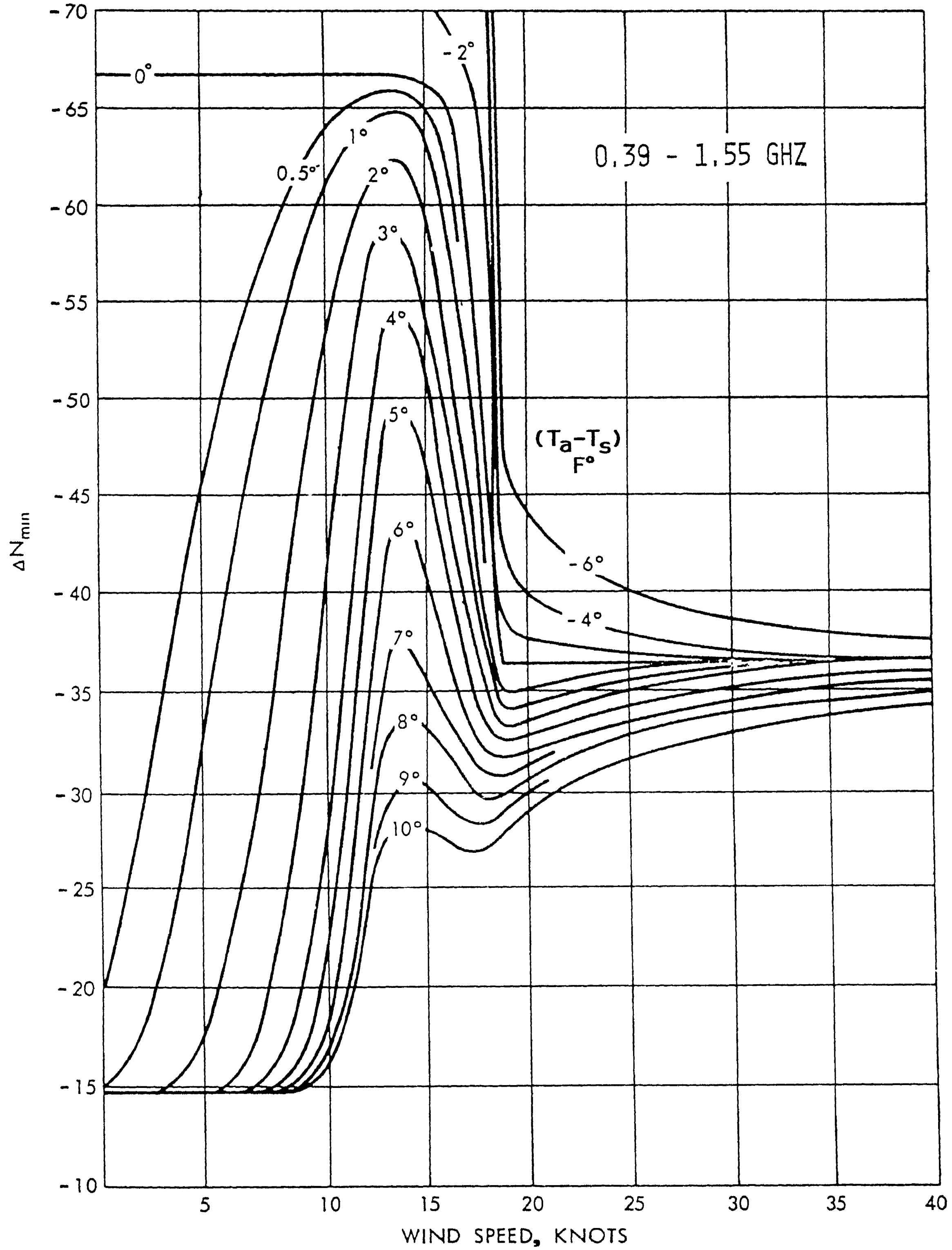
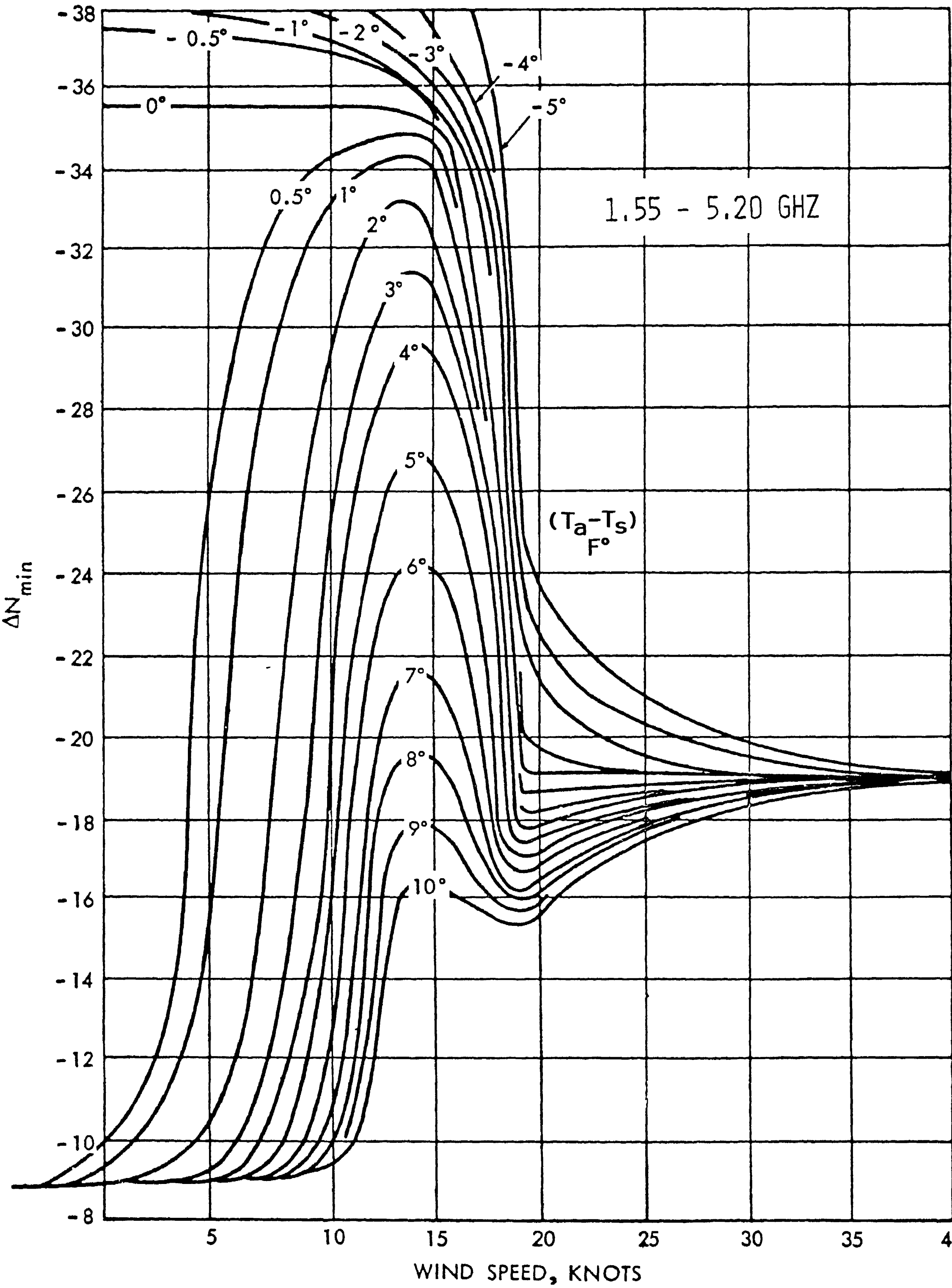


Figure AIII-1.—Ductogram.



$\Delta N_{min.}$ = MINIMUM ΔN REQUIRED FOR A GIVEN WIND SPEED AND $T_a - T_s$ (AIR TEMPERATURE MINUS SEA SURFACE TEMPERATURE), °F

Figure AIII-2A.—Radar frequency diagram.



ΔN_{min} = MINIMUM ΔN REQUIRED FOR A GIVEN WIND SPEED AND $T_a - T_s$ (AIR TEMPERATURE MINUS SEA SURFACE TEMPERATURE), °F

Figure AIII-2B.—Radar frequency diagram.

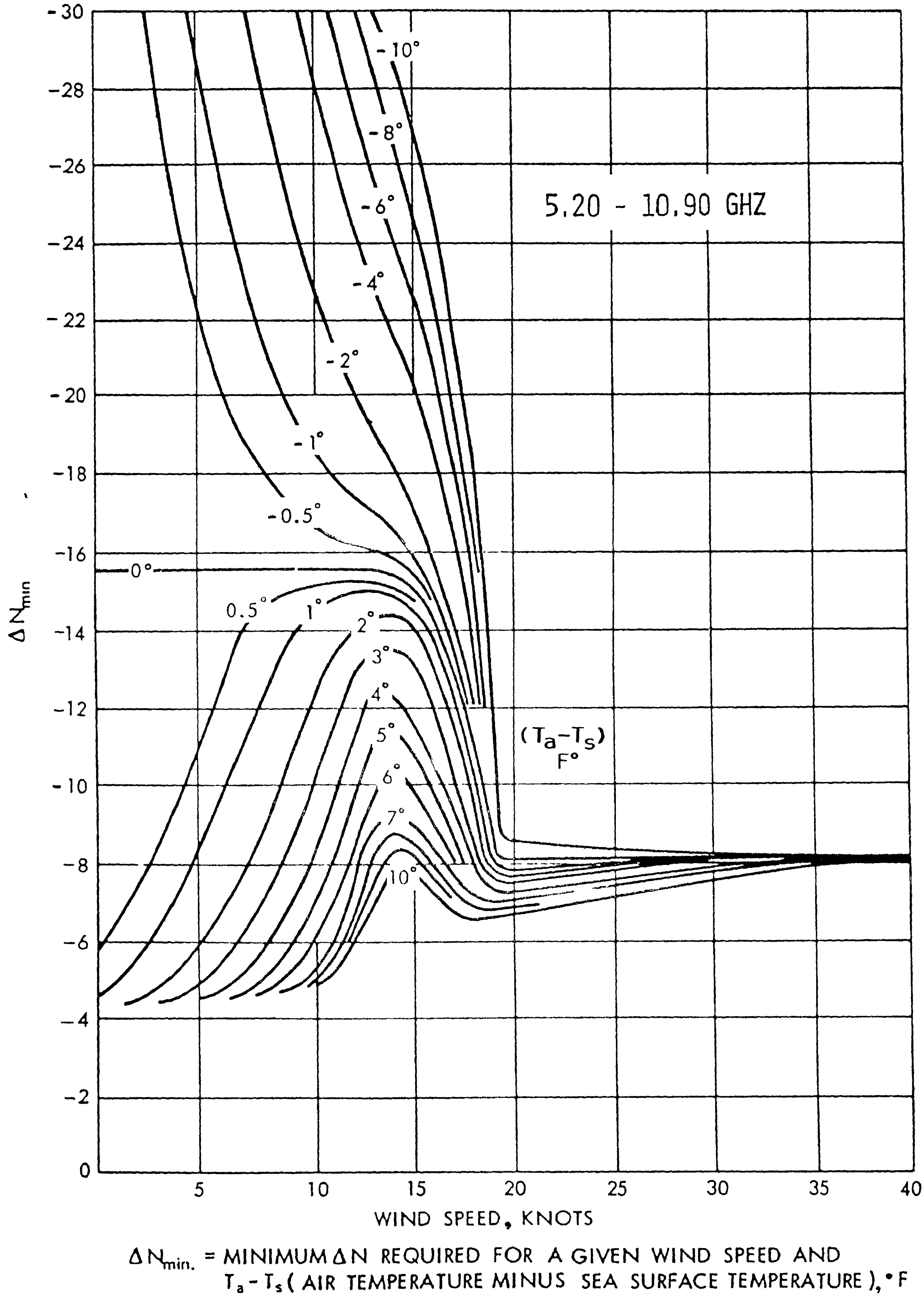


Figure AIII-2C.—Radar frequency diagram.

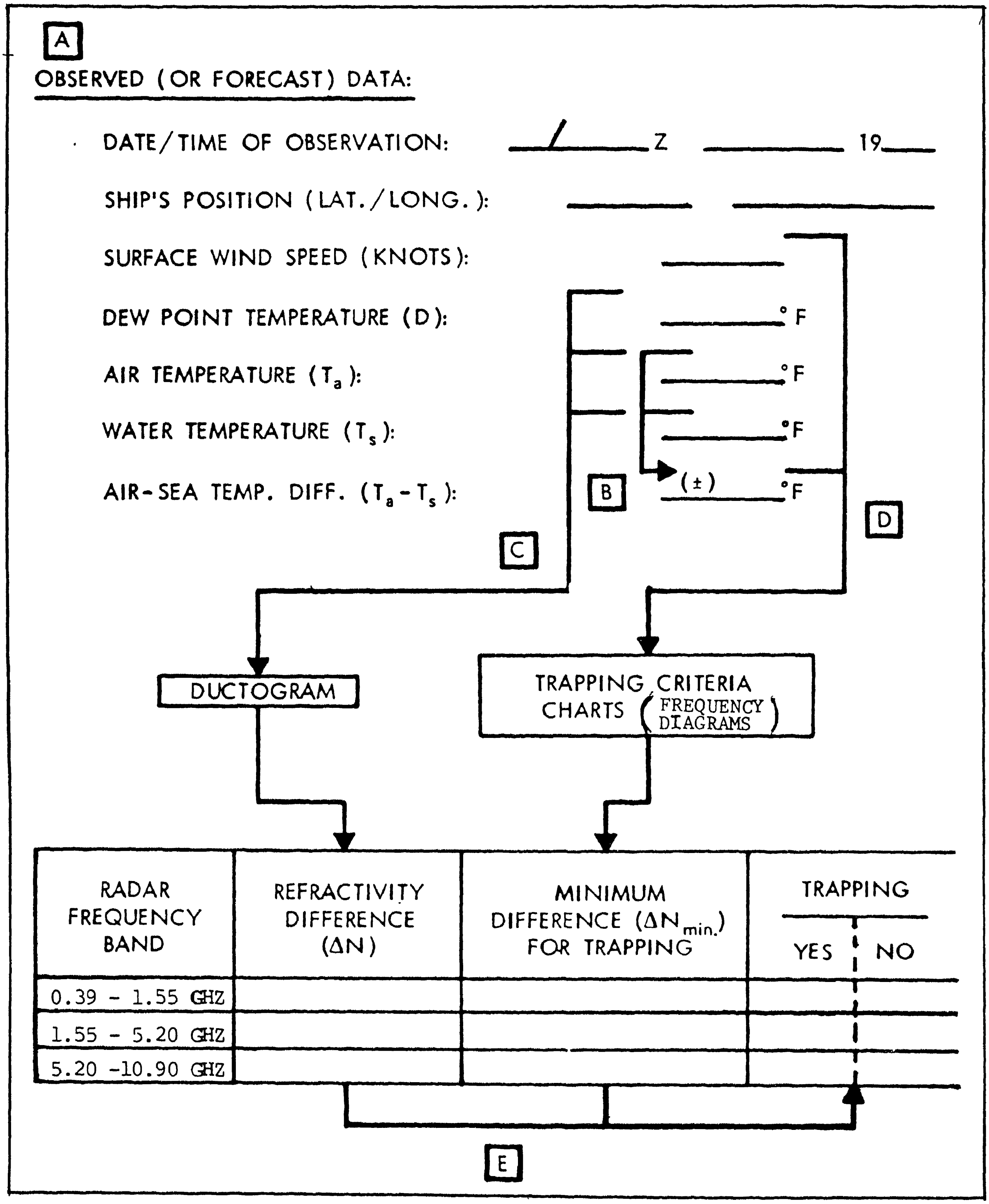


Figure AIII-3.—Ductogram worksheet.

APPENDIX IV

DETERMINING THE EXISTENCE OF RADAR HOLES

The existence of a radar hole may be determined by using the **MODIFIED REFRACTIVE INDEX VALUE** (*M*-value). The value of *M* can be determined by using the formula

$$M = N_h + 0.048h,$$

where h equals height, or by adding 48 *N*-units per 1,000 feet to the actual *N*-unit value. An *N*-value of 308 at an altitude of 500 feet, for example, would have an *M*-value of 332. All *M*-values, for each level (above the surface), will have a higher value than the corresponding *N*-value.

To determine the existence of a radar hole, you must first plot both the *M*-curve and the *N*-curve on a graph.

NOTE: When preparing the graph, make sure two sets of numbers are at the bottom, one for *N*-values and one for *M*-values, as shown in figure AIV-1.

The next step in determining the existence of a radar hole is to locate the base and the top of the TRAPPING LAYER, using the graph; then, obtain the *M*-value at the height of the radar.

If the *M*-value at the base of the trapping layer (M_B) is greater than the *M*-value at radar height (M_r), a radar hole is generally present.

But if M_r is greater than M_B, no radar hole will exist, whether the radar is located above, below, or within the trapping layer.

In figure AIV-2, for example, the base of the trapping layer is at 900 feet (point A on the *N*-curve and point C on the *M*-curve). The *M*-value at the base of the layer (M_B) is 343. Since the radar (h_r) is at 100 feet and the *M*-value at radar height (M_r) is 313, a radar hole may exist.

If the *M*-values indicate that a radar hole may exist, further computations are necessary to verify its existence. The first step is to determine maximum radar height, below which no radar hole will occur. This value is referred to as $h_{r(max)}$ and is determined by the following formula:

$$h_{r(max)} = h_B \frac{0.048h_T - N_S + N_T}{0.048h_B - N_S + N_B},$$

where $h_{r(max)}$ = maximum radar height;

h_B = height of the base of the trapping layer;

h_T = height of the top of the trapping layer;

N_S = *N*-value at the surface;

N_T = *N*-value at the top of the trapping layer and

N_B = *N*-value at the base of the trapping layer.

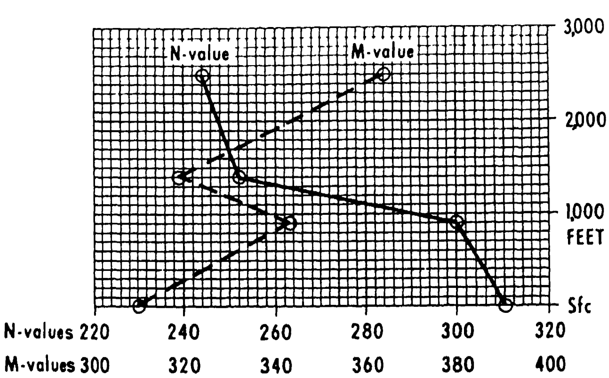


Figure AIV-1.—M- and N-curve plots.

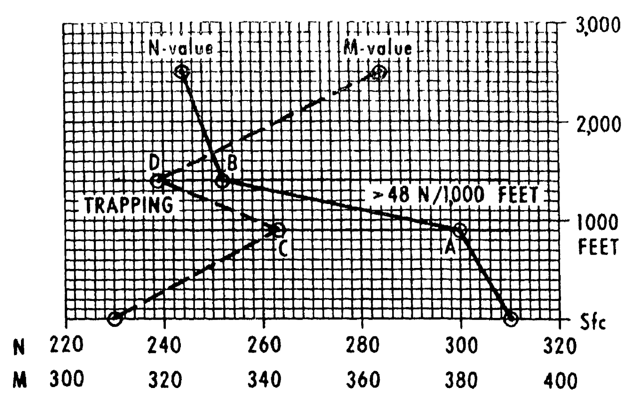


Figure AIV-2.—M-value interpretation.

EXAMPLE

Given the following values, determine the ranges to the near edge and the far edge of the radar hole:

$N_B = 296 \qquad h_B = 3{,}260$

$N_T = 250 \qquad h_T = 3{,}760$

$N_r = 301 \qquad h_r = 3{,}000$

STEP 1:

$$D_1 = \frac{0.232(h_T - h_B)}{N_B - N_T - 0.048(h_T - h_B)}$$

$$= \frac{0.232(3760 - 3260)}{296 - 250 - 0.048(3760 - 3260)}$$

$$= \frac{0.232(500)}{296 - 250 - 0.048(500)}$$

$$= \frac{116}{46 - 24}$$

$D_1 = 5.28$ nautical miles

STEP 2:

$$D_2 = \frac{0.232(h_B - h_r)}{N_r - N_B - 0.048(h_B - h_r)}$$

$$= \frac{0.232(3260 - 3000)}{301 - 296 - 0.048(3260 - 3000)}$$

$$= \frac{0.232(260)}{301 - 296 - 0.048(260)}$$

$$= \frac{60.32}{5 - 12.48}$$

$$= \frac{60.32}{-7.48}$$

$D_2 = -8.07$ nautical miles

STEP 3:

$$\begin{aligned}
R = {} & (D_1 - D_2)\sqrt{N_B - N_T - 0.048(h_T - h_B)} \\
& \pm D_2\sqrt{N_r - N_T - 0.048(h_T - h_r)} \\
= {} & (5.28 - (-8.07))\sqrt{296 - 250 - 0.048(3760 - 3260)} \\
& \pm -8.07\sqrt{301 - 250 - 0.048(3760 - 3000)} \\
= {} & 13.35\sqrt{296 - 250 - 0.048(500)} \\
& \pm -8.07\sqrt{301 - 250 - 0.048(760)} \\
= {} & 13.35\sqrt{46 - 24} \pm -8.07\sqrt{51 - 36.48} \\
= {} & 13.4\sqrt{22} \pm -8.1\sqrt{14.5} \\
= {} & 62.846 \pm 30.8448
\end{aligned}$$

$R = 63 \pm 31$ nautical miles

$R' = 32$ nautical miles

$R'' = 94$ nautical miles

NOTE: Figure AIV-3 depicts a radar hole as it extends upward, away from the trapping layer. Since radar waves emerge tangent to the top of the refractive layer, the radar hole does not increase in width. However, owing to Earth's curvature, the distance to the near edge and to the far edge will increase with altitude. The actual distance is determined by the N-gradient above the layer.

It may be necessary, at times, to find the dimensions of a radar hole at specific altitudes. In order to find these dimensions, you must first find the range beyond the trapping layer top (R_x) using figure AIV-4.

The procedure is as follows:

1. Use the criteria on figure AIV-4 to determine which gradient line to use as follows:

   a. If the N-value above the layer shows very little change with height (the N-gradient is zero), use line 1.

   b. When the N-values above the layer change with height (the N-gradient is other than zero), use the surface N-value (N_s) and the radar height, if necessary, to determine which line to use.

      (1) Use line 2 if the N_s is near 250 units.

      (2) Use line 3 if the N_s is near 400 units and the radar is about 1,000 feet above the surface.

      (3) Use line 4 if the N_s is near 400 units and the radar is about 5,000 feet above the surface.

   c. Interpolate between lines as necessary.

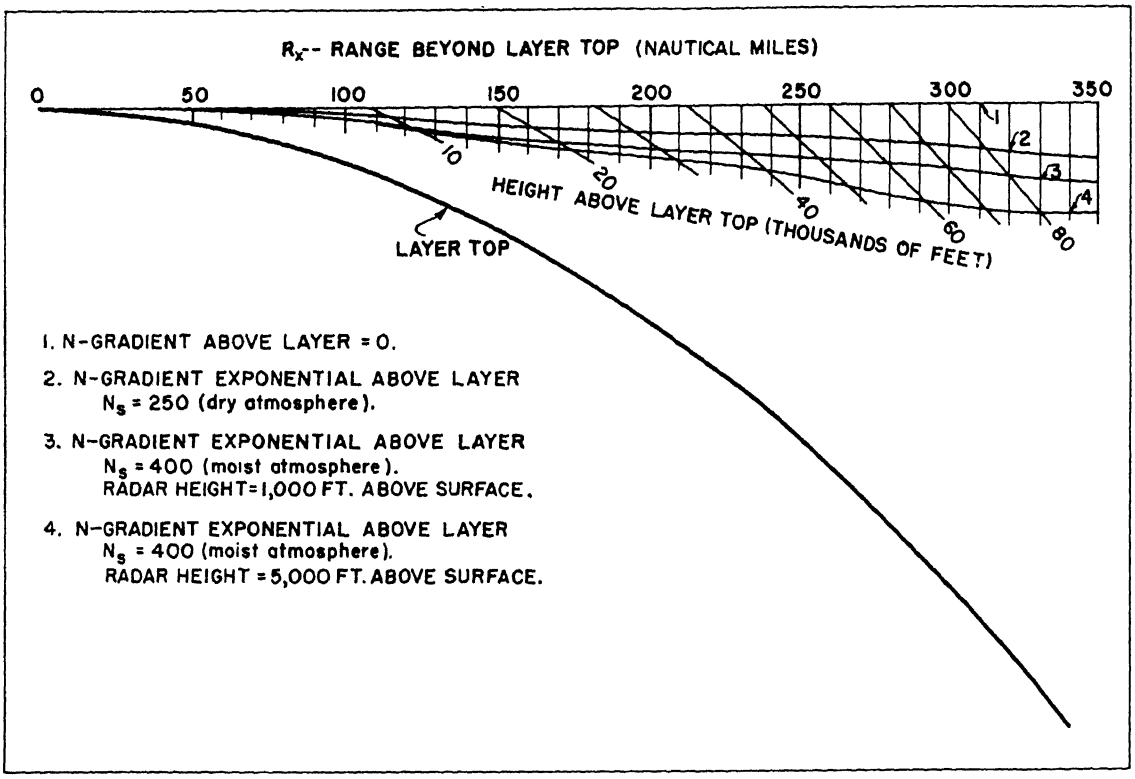


Figure AIV-4.—Range beyond the trapping layer top.

2. Follow the line that indicates the given *height above layer top* diagonally upward to the point where it intersects the *N*-gradient line. Interpolate as necessary.

3. Go vertically upward and read *range beyond layer top* (R_x) at the top of the figure.

EXAMPLE:

Assume that radar height is 2,500 feet and that N_s is 400 units. Determine the range at 32,500 feet AGL (30,000 feet above the layer top).

1. Follow the 30,000′ height line (30) diagonally upward, to about one-third of the way from line 3 to line 4 (interpolated position between line 3 and line 4).

2. From the point of intersection, go vertically upward and read R_x at the top of the figure. (Interpolate as necessary.) You should read a range of 208 nautical miles plus or minus 5.

3. Add R_x (208 nmi) to both R' and R'' to find the range.

Review the steps for determining the dimensions of a radar hole when the radar is located below the trapping layer. Then complete worksheet No. 1. Check your answers with the completed worksheet immediately following worksheet No. 1.

NOTE: Normally, you will not have to perform these calculations; they are provided automatically by the IREPS programs. You should become familiar with them, however, to fully understand the effects of atmospheric refraction. The more thoroughly you understand refractivity, the more accurate and logical your staff briefings will be.

WORKSHEET NO. 1

RADAR BENEATH THE TRAPPING LAYER

Either step A or step B may be used; generally there is no need to use both.

STEP A. For a yes/no determination of the existence of a radar hole:

(1) $M_r = N_r + 0.048h_r$	h_r ________ feet
$= \_\_\_\_\_\_ + 0.048(\_\_\_\_\_\_)$	h_T ________ feet
$M_r = \_\_\_\_\_\_$	h_B ________ feet
(2) $M_B = N_B + 0.048h_B$	$h_{r(max)}$ ________ feet
$= \_\_\_\_\_\_ + 0.048(\_\_\_\_\_\_)$	M_r ________ feet
$M_B = \_\_\_\_\_\_$	M_B ________ feet
	N_B ________ feet
	N_T ________ feet
	N_r ________ feet
	N_S ________ feet

If M_r is greater than M_B, NO HOLE IS PRESENT.

If M_B is greater than M_r, a hole is present; continue computational procedures.

STEP B. For a determination of the height below which no radar hole will be formed:

$$h_{r(max)} = h_B \frac{0.048h_T - N_S + N_T}{0.048h_B - N_S + N_B}$$

$$= (\_\_\_\_\_\_)\frac{0.048(\quad) - (\quad) + (\quad)}{0.048(\quad) - (\quad) + (\quad)}$$

$$= (\_\_\_\_\_\_)\frac{(\qquad\qquad)}{(\qquad\qquad)}$$

$$h_{r(max)} = \_\_\_\_\_\_$$

If $h_{r(max)}$ is equal to or greater than h_r, no radar hole is present.

If $h_{r(max)}$ is less than h_r, a radar hole MAY be present, and computations continue.

STEP C.

$$D_1 = \frac{0.232(h_T - h_B)}{N_B - N_T - 0.048(h_T - h_B)}$$

$$D_1 = \frac{0.232(\qquad)}{(\qquad) - 0.048(\qquad)}$$

$D_1 =$ ____________________

D_1 must be a positive number if a hole is present.

$$D_2 = \frac{0.232(h_B - h_r)}{N_r - N_B - 0.048(h_B - h_r)}$$

$$D_2 = \frac{0.232(\qquad)}{(\qquad) - 0.048(\qquad)}$$

$D_2 =$ ____________________

D_2 will usually be a negative number.

STEP D.

$$R = (D_1 - D_2)\sqrt{N_B - N_T - 0.048(h_T - h_B)}$$

$$\pm D_2\sqrt{N_r - N_T - 0.048(h_T - h_r)}$$

$$= (\underline{\qquad})\sqrt{(\underline{\qquad}) = 0.048(\underline{\qquad})}$$

$$\pm (\underline{\qquad})\sqrt{(\underline{\qquad}) = 0.048(\underline{\qquad})}$$

$$= (\underline{\qquad})\sqrt{(\underline{\qquad})} \pm (\underline{\qquad})\sqrt{(\underline{\qquad})}$$

$R = (\underline{\qquad\qquad}) \pm (\underline{\qquad\qquad})$

$R' =$ ____________

$R'' =$ ____________

At any point where it becomes necessary to determine the square root of a *negative* number, the hole would then be imaginary, and computations should cease.

STEP E.

(1) Compute and record the additive values for each listed altitude, using the given gradient-above-the-layer and figure AIV-3.

(2) Add the computed values to R' for beginning of hole (BOH) and to R'' for end of hole (EOH) for each listed altitude.

ALTITUDE	BOH	EOH
____ feet (h_T)	____ nmi (R′)	____ nmi (R″)
5,000 feet	____ nmi (R′ +)	____ nmi (R″ +)
10,000 feet	____ nmi (R′ +)	____ nmi (R″ +)
15,000 feet	____ nmi (R′ +)	____ nmi (R″ +)
20,000 feet	____ nmi (R″ +)	____ nmi (R″ +)
25,000 feet	____ nmi (R′ +)	____ nmi (R″ +)
30,000 feet	____ nmi (R′ +)	____ nmi (R″ +)
35,000 feet	____ nmi (R′ +)	____ nmi (R″ +)
40,000 feet	____ nmi (R′ +)	____ nmi (R″ +)

ANSWERS TO WORKSHEET NO. 1

RADAR BENEATH THE TRAPPING LAYER

STEP A. For a yes/no determination of the existence of a radar hole:

(1) $M_r = N_r + 0.048h_r$	h_r 600 feet
$= \underline{\ 318\ } + 0.048(\underline{\ 600\ })$	h_T 1,200 feet
$M_r = \underline{346.8}$	h_B 800 feet
(2) $M_B = N_B + 0.048h_B$	$h_{r(max)}$ 516 feet
$= \underline{\ 316\ } + 0.048(\underline{\ 800\ })$	M_r 346.8 feet
$M_B = \underline{354.4}$	M_B 354.4 feet
	N_B 316 feet
	N_T 286 feet
	N_r 318 feet
	N_s 324 feet

If M_r is greater than M_B, NO HOLE IS PRESENT.

If M_B is greater than M_r, a hole is present; continue computational procedures.

STEP B. For a determination of the height below which no radar hole will be formed:

$$h_{r(max)} = h_B \frac{0.048h_T - N_S + N_T}{0.048h_B - N_S + N_B}$$

$$= (\underline{\ 800\ }) \frac{0.048(1200) - (324) + (286)}{0.048(\ 800) - (324) + (316)}$$

$$= (\underline{\ 800\ }) \frac{(19.6)}{(30.4)}$$

$h_{r(max)} = \underline{\ 515.8\ }$

If $h_{r(max)}$ is equal to or greater than h_r, no radar hole is present.

If $h_{r(max)}$ is less than h_r, a radar hole MAY be present, and computations continue.

STEP C.

$$D_1 = \frac{0.232(h_T - h_B)}{N_B - N_T - 0.048(h_T - h_B)}$$

$$D_1 = \frac{0.232(1200 - 800)}{(316 - 286) - 0.048(1200 - 800)}$$

$$D_1 = \underline{\ 8.6\ }$$

D_1 must be a positive number for a hole to be present.

$$D_2 = \frac{0.232(h_B - h_r)}{N_r - N_B - 0.048(h_B - h_r)}$$

$$D_2 = \frac{0.232(800 - 600)}{(318 - 316) - 0.048(800 - 600)}$$

$$D_2 = \underline{\ -6.1\ }$$

D_2 will usually be a negative number.

STEP D.

$$R = (D_1 - D_2)\sqrt{N_B - N_T - 0.048(h_T - h_B)}$$

$$\pm\ D_2\sqrt{N_r - N_T - 0.048(h_T - h_r)}$$

$$= \underline{(8.6 - (-6.1)}\sqrt{\underline{(316 - 286)} - 0.048\underline{(1200 - 800)}}$$

$$\pm\ \underline{(-6.1)}\sqrt{\underline{(318 - 286)} - 0.048\underline{(1200 - 600)}}$$

$$= \underline{(14.7)}\sqrt{\underline{(10.8)}} \pm \underline{(-6.1)}\sqrt{\underline{(3.2)}}$$

$$R = \underline{(48.3)} \pm \underline{(-10.9)}$$

$$R' = \underline{\ 37.4\ }$$

$$R'' = \underline{\ 59.2\ }$$

At any point when it becomes necessary to determine the square root of a negative number, the hole would then be imaginary and computations cease.

STEP E. To determine the shape of the radar hole:

(1) Compute and record the additive values for each listed altitude, using the given gradient-above-the-layer and a refractive index worksheet.

(2) Add the computed values to R' for beginning of hole and to R'' for end of hole for each listed altitude.

ALTITUDE	BOH	EOH
1,200 feet (h_T)	37.4 nmi (R′)	59.2 nmi (R″)
5,000 feet	117.4 nmi (R′ + 80)	139.2 nmi (R″ + 80)
10,000 feet	149.4 nmi (R′ + 112)	171.2 nmi (R″ + 112)
15,000 feet	174.4 nmi (R′ + 137)	196.2 nmi (R″ + 137)
20,000 feet	194.4 nmi (R″ + 160)	219.2 nmi (R″ + 160)
25,000 feet	215.4 nmi (R′ + 178)	237.2 nmi (R″ + 178)
30,000 feet	231.4 nmi (R′ + 194)	253.2 nmi (R″ + 194)
35,000 feet	245.4 nmi (R′ + 208)	267.2 nmi (R″ + 208)
40,000 feet	260.4 nmi (R′ + 223)	282.2 nmi (R″ + 223)

TOLERANCE FOR ADDITIVE VALUES IS ±2.

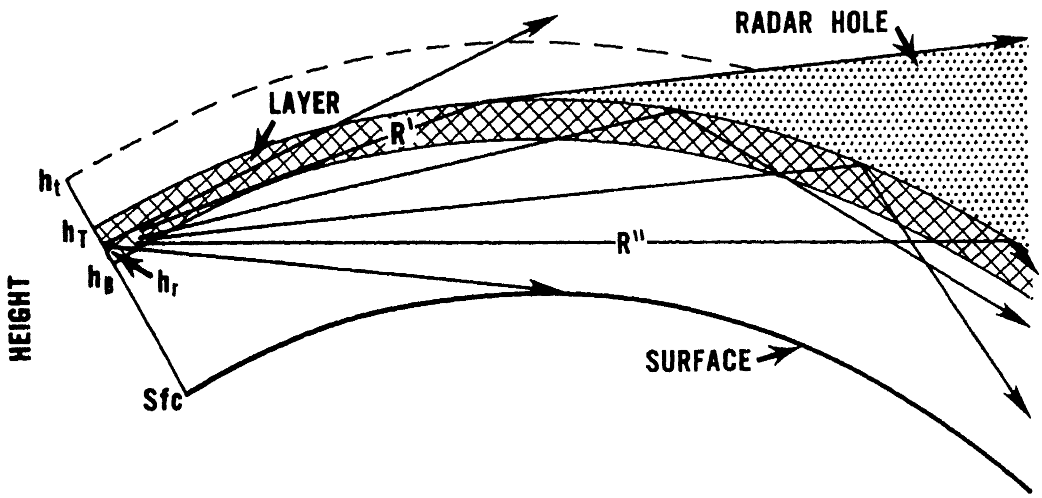


Figure AIV-5.—Radar located within the trapping layer.

RADAR WITHIN THE TRAPPING LAYER

The N-gradient immediately above the ocean's surface will be considerably stronger than −48 N-units per 1,000 feet, forming an **OCEANIC EVAPORATIVE DUCT**. This layer is generally quite shallow, with the average top approximately 10 feet above the surface.

Submariners frequently use these surface ducts to extend their radar range, often up to 5 times beyond normal range. See figure AIV-5.

The formula below is used to determine the distance to the near edge of the radar hole when the radar is located within the trapping layer. Since the presence of a radar hole shortens the normal radar horizon, no calculations are necessary to determine the far edge of the hole.

$$R' = h_T\sqrt{\frac{2}{N_S - N_T - 0.048h_T}}$$

Using the data given below, complete worksheet No. 2. Round off your answers to the nearest hundredth. Check your answers to step A with the completed worksheet immediately following worksheet No. 2 before continuing to step B.

HEIGHT (ft)	N-VALUE
surface	332 (N_S)
600	310
900	274 (N_T)
2,200	257

Radar height = 800 feet
N-gradient above layer = 250
Top of trapping layer = 900 feet

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WORKSHEET NO. 2

RADAR WITHIN THE LAYER

STEP A.

h_T ______

N_S ______

N_T ______

$$R' = h_T\sqrt{\frac{2}{N_S - N_T - 0.048h_T}}$$

$$= (\_\_\_\_\_)\sqrt{\frac{2}{(\_\_\_\_\_\_\_) - 0.048(\_\_\_\_)}}$$

$$R' = (\_\_\_\_\_)\sqrt{\_\_\_\_\_\_\_\_\_\_\_\_\_\_}$$

$$R' = \_\_\_\_\_\_$$

Any time the term under the square root is a negative number, the hole will be imaginary. (This occurs frequently.)

STEP B.

ALTITUDE	BOH
_____ feet (h_T)	_____ nmi (R′)
5,000 feet	_____ nmi (R′ + 80)*
10,000 feet	_____ nmi (R′ + 112)
15,000 feet	_____ nmi (R′ + 137)
20,000 feet	_____ nmi (R′ + 160)
25,000 feet	_____ nmi (R′ + 178)
30,000 feet	_____ nmi (R′ + 194)
35,000 feet	_____ nmi (R′ + 208)
40,000 feet	_____ nmi (R′ + 223)

* Additive values for "*N*-gradient above layer" of 250 are provided.

ANSWERS TO WORKSHEET NO. 2

RADAR WITHIN THE LAYER

STEP A.

h_T 900

N_S 332

N_T 274

$$R' = h_T\sqrt{\frac{2}{N_S - N_T - 0.048h_T}}$$

$$= (\underline{900})\sqrt{\frac{2}{(\underline{332 - 274}) - 0.048(\underline{900})}}$$

$$R' = (\underline{900})\sqrt{0.135135}$$

$$R' = \underline{333}$$

Any time the term under the square root is a negative number, the hole will be imaginary. (This occurs frequently.)

STEP B.

ALTITUDE	BOH
900 feet (h_T)	333 nmi (R′)
5,000 feet	413 nmi (R′ + 80)*
10,000 feet	445 nmi (R′ + 112)
15,000 feet	470 nmi (R′ + 137)
20,000 feet	493 nmi (R′ + 160)
25,000 feet	511 nmi (R′ + 178)
30,000 feet	527 nmi (R′ + 194)
35,000 feet	541 nmi (R′ + 208)
40,000 feet	556 nmi (R′ + 223)

* Additive values for "*N*-gradient above layer" of 250 are provided.

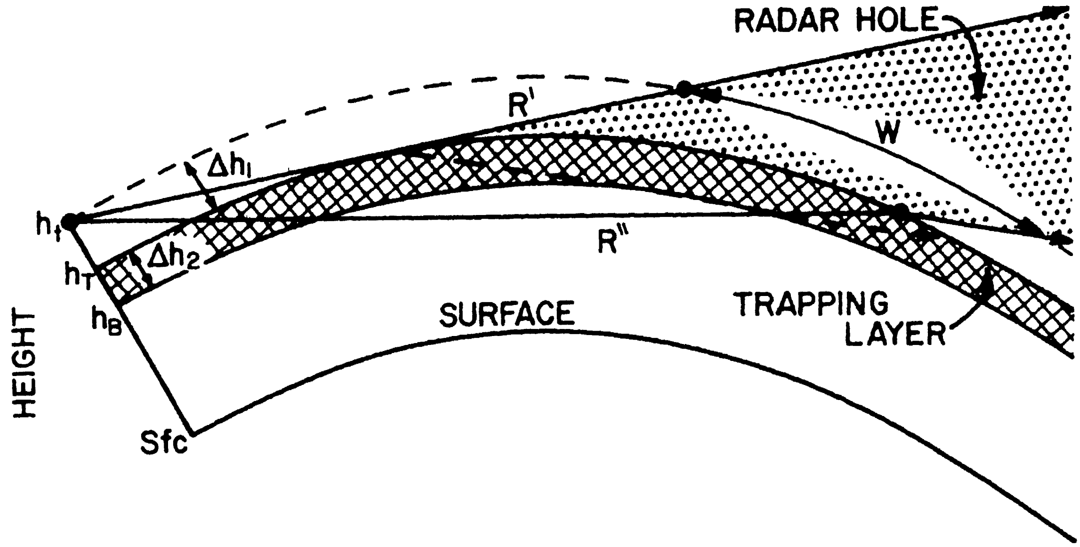

Figure AIV-6.—Radar located above the trapping layer.

RADAR ABOVE THE TRAPPING LAYER

Within seconds, aircraft can be above, below, or within an elevated trapping layer. This shift in altitude can cause some unique radar problems for the pilot. In addition to determining the favored and/or required altitude for maximum aircraft and radar performance, he must also know the exact radar height necessary to place the radar hole at maximum radar range. Since energy is refracted from the trapping layer, areas adjacent to the radar hole will have increased energy amounts, thus providing added definition to any target at maximum radar range. See figure AIV-6.

Given the following information, use the formulas on worksheet No. 3 to find h_r, R' (beginning of radar hole), and R'' (end of radar hole) when the radar is located above an elevated trapping layer.

HEIGHT (ft)	N-VALUE
surface	340
300	336
800	304
1,500	289

Radar height = 1,300 feet

NOTE: In step A, determine square root to the nearest hundredth.

In step B, find C_2 and C_1 to the nearest thousandth.

Find the ratio C_2/C_1 to the nearest thousandth. Round all other answers to the nearest tenth.

In step C, find the ratio $\Delta h_1/\Delta h_2$.

In step D, use figure AIV-7 to determine the WIDTH OF THE RADAR HOLE as follows:

1. Follow the vertical line upward from the bottom of the chart along the value of C_2/C_1 obtained in Step B.

2. Follow the horizontal line from the left side of the chart along the $\Delta h_1/\Delta h_2$ value obtained in step C.

3. Read the value of the curved line (W/R') at the intersection of the two values. Interpolate between lines as necessary.

Check your answers for each step before proceeding to the next step. (Answers follow worksheet No. 3.)

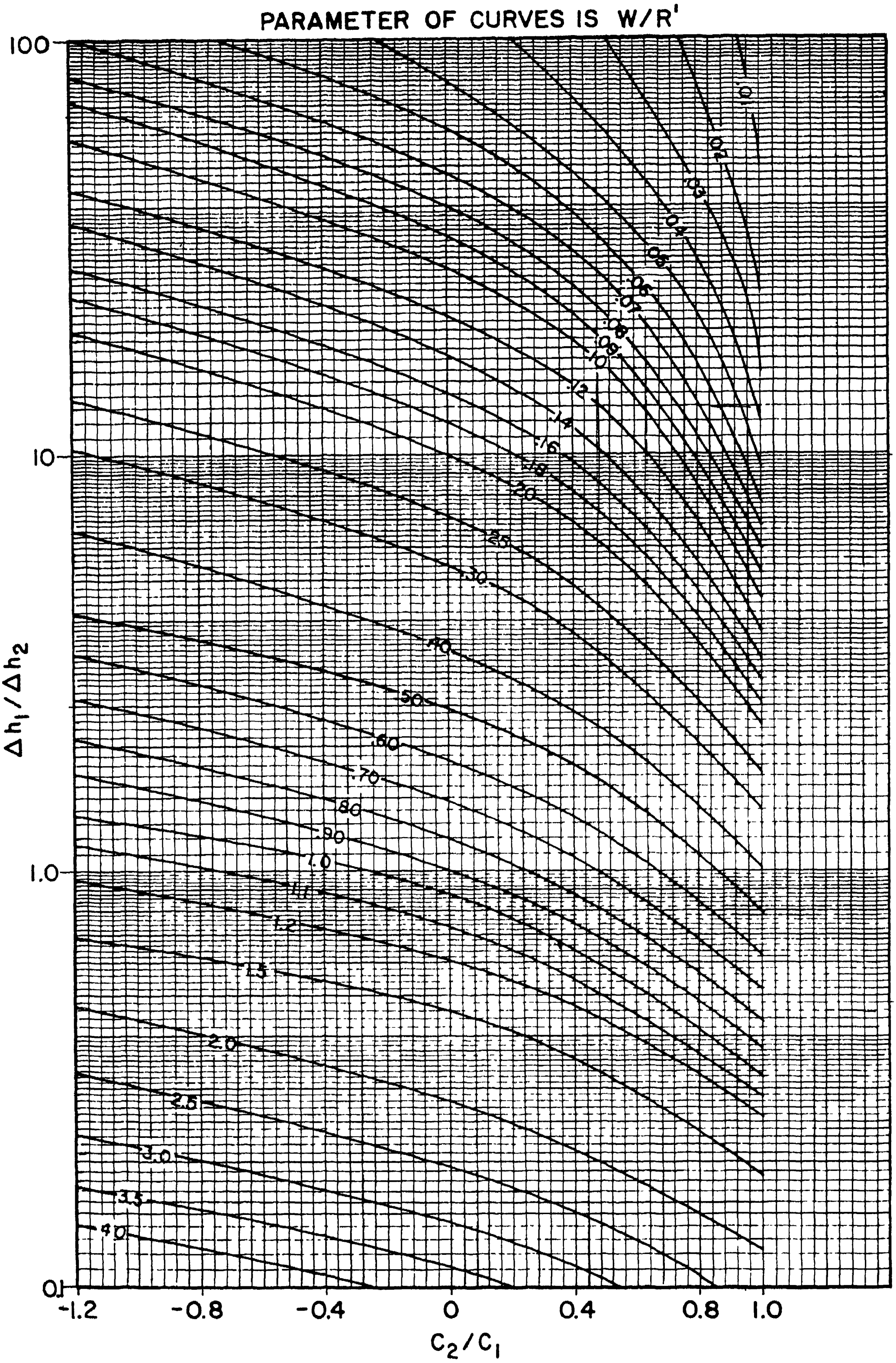

Figure AIV-7.—Width of radar hole.

WORKSHEET NO. 3

RADAR ABOVE TRAPPING LAYER

STEP A. Determine the near edge of the radar hole (R') at the height of the radar antenna (h_r)

h_r ________

h_T ________

h_B ________

N_T ________

N_r ________

N_B ________

$$R' = \frac{0.465(h_r - h_T)}{\sqrt{0.048(h_r - h_T) - (N_T - N_r)}}$$

$$= \frac{0.465(\qquad\qquad)}{\sqrt{0.048(\underline{\qquad\qquad}) - (\underline{\qquad\qquad})}}$$

$R' =$ ________

If R' is a negative number, the hole is imaginary.

STEP B.

(1)

$$C_2 = \frac{N_T - N_B}{h_T - h_B} + 0.048$$

$$= \frac{(\qquad)}{(\qquad)} + 0.048$$

$C_2 =$ ________

(2)

$$C_1 = \frac{N_R - N_T}{H_r - h_T} + 0.048$$

$$= \frac{(\qquad)}{(\qquad)} + 0.048$$

$C_1 =$ ________

(3)

$$\frac{C_2}{C_1} = \frac{(\qquad\qquad\qquad)}{(\qquad\qquad\qquad)}$$

$=$ ________________

STEP C.

(1)

$\Delta h_1 = h_r - h_T$

$= (\_\_\_\_\_) - (\_\_\_\_\_)$

$\Delta h_1 =$ _____

(2)

$\Delta h_2 = h_T - h_B$

$= (\_\_\_\_\_) - (\_\_\_\_\_)$

$\Delta h_2 =$ _____

(3)

$\frac{\Delta h_1}{\Delta h_2} =$ _________

$\frac{\Delta h_1}{\Delta h_2} =$ _________

STEP D.

(1) Enter figure AIV-7, and obtain the ratio W/R'.

(2) $W = R'(W/R')$

$W = (\_\_\_\_\_\_\_) \times (\_\_\_\_\_\_\_)$

$W =$ _______

STEP E.

$R'' = R' + W$

$= (\_\_\_\_\_\_\_) + (\_\_\_\_\_\_\_)$

$R'' =$ _______

STEP F.

ALTITUDE	BOH	EOH
______ feet (h_r)	______ nmi (R′)	______ nmi (R″)

TOLERANCE FOR BOH IS ±1 AND FOR EOH, ±2.

ANSWERS TO WORKSHEET NO. 3

RADAR ABOVE TRAPPING LAYER

STEP A. Determine the near edge of the radar hole (R') at the height of the radar antenna (h_r)

h_r 1,300

h_T 800

h_B 300

N_T 304

N_r 293

N_B 336

$$R' = \frac{0.465(h_r - h_T)}{\sqrt{0.048(h_r - h_T) - (N_T - N_r)}}$$

$$= \frac{0.465(500)}{\sqrt{0.048(\underline{\ 500\ }) - (\underline{\ 11\ })}}$$

$$= \frac{232.5}{3.61}$$

$$R' = \underline{\ 64.4\ }$$

If R' is a negative number, the hole is imaginary.

STEP B.

(1)

$$C_2 = \frac{N_T - N_B}{h_T - h_B} + 0.048$$

$$= \frac{(\ -32\ )}{(\ 500\ )} + 0.048$$

$$C_2 = \underline{\ -.016\ }$$

(2)

$$C_1 = \frac{N_R - N_T}{h_r - h_T} + 0.048$$

$$= \frac{(\ -11\ )}{(\ 500\ )} + 0.048$$

$$C_1 = \underline{\ .026\ }$$

(3)

$$\frac{C_2}{C_1} = \frac{(\ -.016\ )}{(\ .026\ )}$$

$$= \underline{\ -0.615\ }$$

STEP C.

(1)

$\Delta h_1 = h_r - h_T$

$= (\underline{\ 1300\ }) - (\underline{\ 800\ })$

$\Delta h_1 = \underline{\ 500\ }$

(2)

$\Delta h_2 = h_T - h_B$

$= (\underline{\ 800\ }) - (\underline{\ 300\ })$

$\Delta h_2 = \underline{\ 500\ }$

(3)

$$\frac{\Delta h_1}{\Delta h_2} = \frac{500}{500}$$

$$\frac{\Delta h_1}{\Delta h_2} = \underline{\ 1.0\ }$$

STEP D.

(1) Refer to figure AIV-7, and obtain the ratio W/R'.

(2) $W = R'(W/R')$

$W = (\underline{\ 64.4\ }) \times (\underline{\ 1.07\ })$

$W = \underline{\ 68.9\ }$

STEP E.

$R'' = R' + W$

$= (\underline{\ 64.4\ }) + (\underline{\ 68.9\ })$

$R'' = \underline{\ 133.3\ }$

STEP F.

ALTITUDE	BOH	EOH
1,300 feet (h_r)	64.4 nmi (R′)	133.3 nmi (R″)

TOLERANCE FOR BOH IS ±1 AND FOR EOH, ±2.

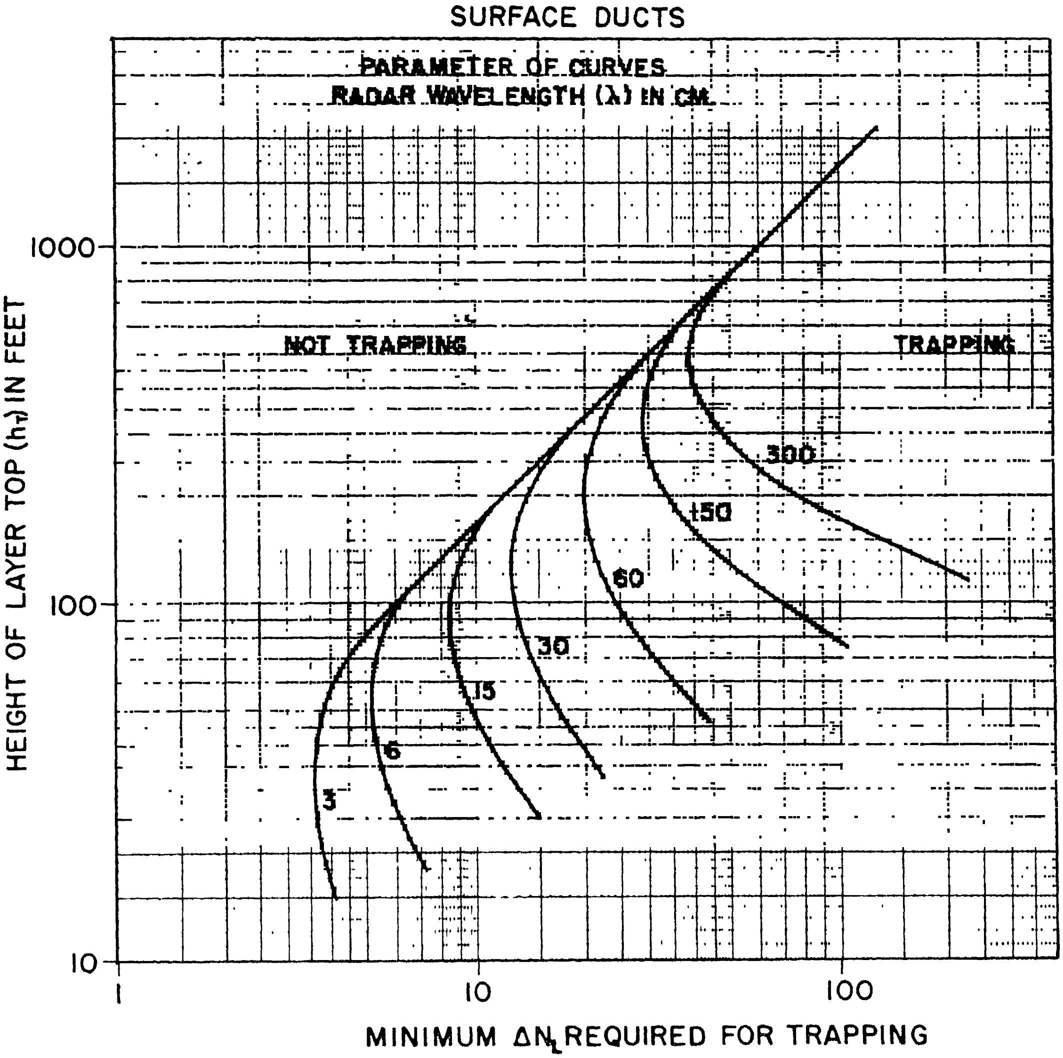

Figure AIV-8.—Trapping criteria for surface and elevated layers.

TRAPPING CRITERIA FOR SPECIFIC RADAR WAVELENGTHS

Often, it is helpful and/or necessary to know whether a specific radar wavelength will be affected by specific N-values at the top of the trapping layer. This can be determined using figure AIV-8, trapping criteria for surface and elevated layers.

On this chart, the vertical lines represent ΔN_L, which is the N-value at the base of the layer minus the N-value at the top of the layer (N_B – N_T). The horizontal lines represent the height of the layer top.

To determine if a particular radar frequency will be affected by a specific N-value, follow ΔN_L upward to the point where it intersects h_T. IF THE POINT OF INTERSECTION IS TO THE RIGHT OF THE WAVELENGTH IN QUESTION, THEN RADAR WILL BE AFFECTED.

EXAMPLE:

Given the following data, determine whether a radar frequency of 150 centimeters will be affected by trapping.

$N_T = 263$

$N_B = 288$

$h_T = 600$ feet

$N_B - N_T = 25$, so follow the 25 N line upward to 600 feet.

The point of intersection is to the left of the 150-centimeter frequency curve; therefore, trapping will not affect radar at that frequency.

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